ARIZONA DEPARTMENT OF TRANSPORTATION

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ANALYSIS OF TEMPORAL DEMAND SHIFTS TO IMPROVE HIGHWAY SPEED MODELING

Final Report

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16. ABSTRACT

In the past ten years, there has been a clear trend away from federal funding of transportation projects. An increasing share of the cost of highways and public transportation must now be borne by state and local governments for whom generating the necessary revenue is far more politically sensitive, and therefore, more difficult. With the shift to state and local finance has come not only an increase in the detail by which capacity needs are evaluated but also an increase in the concern about the benefits that are gained from improvements. Travel time savings, air quality improvements, and improvements in traffic safety are all being examined with greater attention to quantitative estimation. For that reason, it is important that modeling systems accurately predict not only the volume of travel during the periods of peak demand but also the speed at which that travel will occur.

This report presents the results of research on the phenomenon of peak-spreading on congested roadways conducted for the Arizona Transportation Research Center (ATRC) of the Arizona Department of Transportation.

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1.0 OVERVIEW

In the past ten years, there has been a clear trend away from federal funding of transportation projects. An increasing share of the cost of highways and public transportation must now be borne by state and local governments for whom generating the necessary revenue is far more politically sensitive, and therefore, more difficult. With the shift to state and local finance has come not only an increase in the detail by which capacity needs are evaluated but also an increase in the concern about the benefits that are gained from improvements. Travel time savings, air quality improvements, and improvements in traffic safety are all being examined with greater attention to quantitative estimation. For that reason, it is important that modeling systems accurately predict not only the volume of travel during the periods of peak demand but also the speed at which that travel will occur.

This report presents the results of research on the phenomenon of peak-spreading on congested roadways conducted for the Arizona Transportation Research Committee (ATRC) of the Arizona Department of Transportation. The research was conducted using a national cross-section of data but with specific application to the Phoenix metropolitan area. The research was designed to result in recommended changes to the UTPS-based forecasting system used by the Maricopa Association of Governments (MAG) Transportation Planning Office which would allow them to reflect peak-spreading phenomena in future-year forecasting.

Considerable research has been conducted on the impacts of time of day on travel volumes, facility speeds, and trip-making behavior. Variations of traffic volumes over the hours of the day have long been observed, and typical patterns for specific types of facilities in a range of urban contexts are provided in the transportation literature (1,2). Similarly, relationships between facility speeds and volumes have been studied extensively, and a range of mathematical functions have been proposed to represent these relationships (3,4). More recently, behavioral approaches to travel modeling have focused on how individual travelers make their travel choices, including in many cases considerations of time of day (5,6,7,8).

There has also been considerable research on the incorporation of travel choice theory into network modeling systems (9,10,11). A major deficiency, however, has been in the area of incorporating peak-spreading as a result of traffic congestion into the large-scale traffic assignment and network equilibrium systems, such as UTPS, required for detailed highway system analysis in major metropolitan areas. Because these modeling systems cannot feasibly be applied at the behavioral or individual traveler level, the focus in this project was limited to identifying and implementing aggregate representations of peak-spreading phenomena.

The most common practice in modeling peak-hour travel is to produce a twenty-four-hour assignment and predict peak-hour trips as a constant percentage of the twenty-four-hour volume (often ten percent). Some agencies have developed peak-period models by using the percentage of each trip type that occurs during a peak period to create a peak-period trip table (12), but even using this approach, the percentage of travel occurring in the peak one-hour period is generally a fixed percentage of the peak period and no effort is made to relate peaking characteristics to the anticipated level of congestion for the assignment. The result is generally an over-prediction of the peak-hour volume and often an under-prediction of peak-hour speeds.

The approach in the research for ATRC has been to improve the overall modeling of peak-period volumes and speeds by attempting to increase the accuracy of modeling in three areas:

1. modeling of the peak periods,
2. modeling of peak-spreading within the peak periods as a facility becomes congested, and
3. modeling of peak-hour speeds.

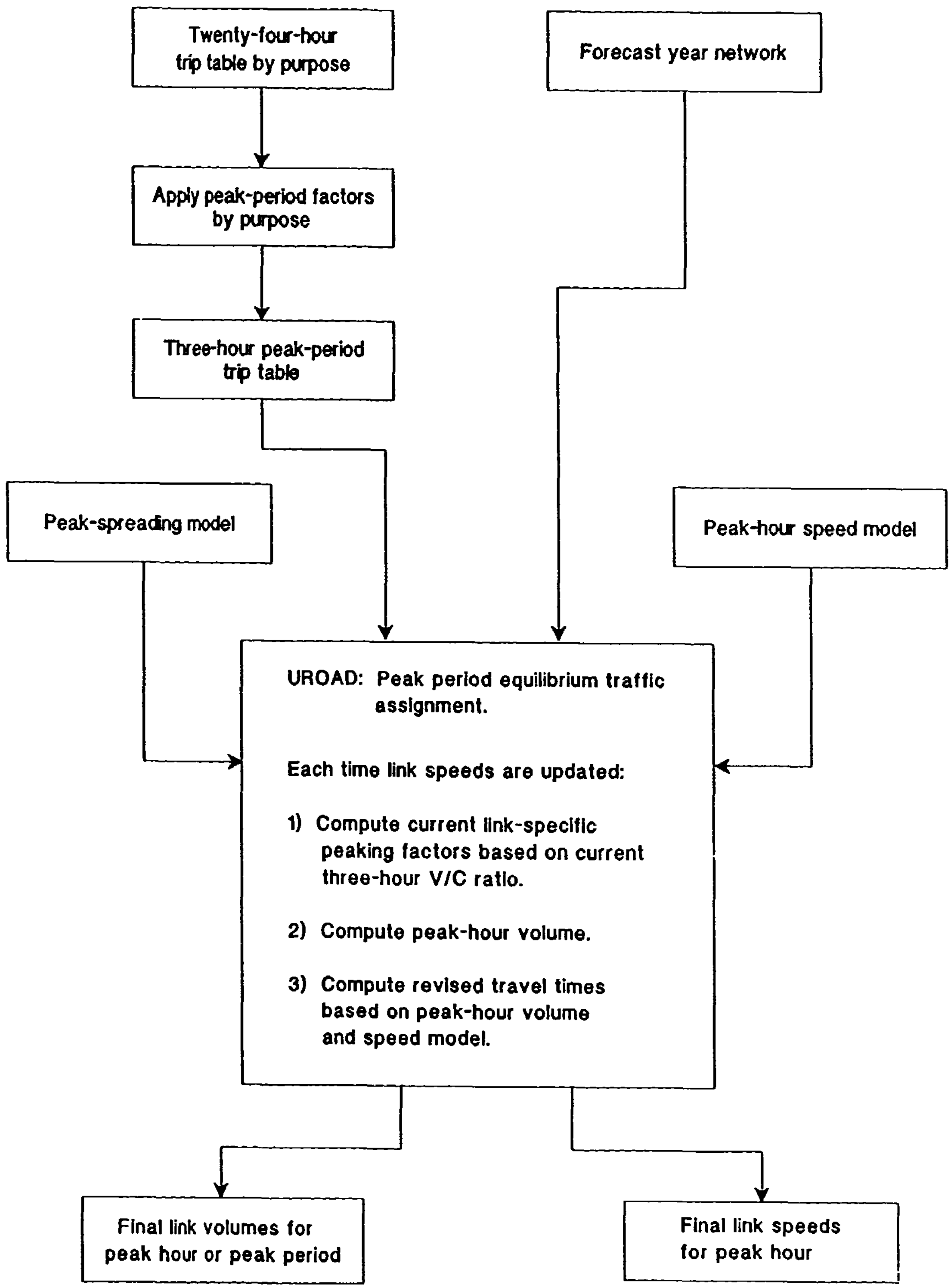
The modeling process which was recommended to implement the research findings of the project is illustrated in Figure 1. The first step in the process is to produce separate trip tables for each of the three time periods: a three-hour A.M. peak, a three-hour P.M. peak, and an off-peak which includes all other times. For MAG, this step is implemented using UMATRIX but other matrix manipulation programs could be used.

The actual forecasting of peak-spreading in the package being implemented for MAG occurs within UROAD. Following development of new peak-spreading models and peak-hour volume-speed models described in this report, an augmented version of the UROAD network equilibrium traffic assignment program was prepared. In this program the new peak-spreading and volume-speed models are applied to each link each time link speed updating is required. The added steps consist of the following:

- Compute ratio of current assigned (three-hour) volume to three-hour link capacity;
- Apply peak-spreading model to provide peaking factor: the ratio of one-hour volume to three-hour volume;
- Determine peak-hour volume as the product of the peaking factor and the assigned three-hour volume;

FIGURE 1.

STRUCTURE OF METHODOLOGY FOR MODEL ENHANCEMENT



- Compute ratio of peak-hour volume to hourly link capacity; and
- Apply peak-hour speed model to estimate revised link speed.

This link updating process continues throughout the iterative equilibrium procedure.

When the network assignment is complete, link volumes represent peak-period (three-hour) flows, but link speeds correspond to peak-hour conditions. The UROAD modifications provide the option, at this point, either to use the peak spreading model to determine a final set of peak-hour volumes, or to retain the peak period volumes.

Two alternative methods for enhacing peak-hour assignments were also developed for MAG for comparison to the method described above. Both involve using 24-hour trip tables rather than 3-hour trip tables. These alternative methods are described in Section 3 and a comparison of the performance of all three methods with MAG's current procedures is provided in Section 5.

The remainder of this report is divided into four sections. Section 2 describes the development of peak period (3-hour) trip tables and Section 3 presents the results of research on peak-spreading and the recommended peak-spreading models. Section 4 presents the research results for peak-hour speed modeling and the recommended models. A validation of the recommended procedures is presented in Section 5 along with a discussion of the transferability of the recommended models to other metropolitan areas.

2.0 MODELING OF PEAK PERIODS

The process by which peak-period assignments are to be produced begins with the division of total daily travel by trip purpose in three periods.

A.M. Peak - 6:00 A.M. to 9:00 A. M.

P.M. Peak - 3:00 P.M. to 6:00 P.M.

Off-Peak - All other hours

The division into these periods is based primarily on the reported time of travel by trip purpose by respondents in the 1981 Household Survey. Two additional data sources were used for trip purposes not covered in the household survey: traffic counts collected at Sky Harbor Boulevard for trips to and from the airport and the Phoenix External Trip Survey for trips entering or leaving the study area (external-external and external-internal trips).

Although more detailed trip classifications were available from the actual survey records, trip purpose categories for this project were limited to those presently used in the MAGTPO modeling process:

Home-Based Work

Home-Based Shop

Home-Based School

Home-Based Other

Non-Home-Based

External-Internal

External-External

Airport Trips

For all home-based trips, a distinction was made between trips made from the home (production to attraction, or P to A) and trips made to home (A to P). Frequency distributions were calculated using three different measures of travel volume:

- Trips
- Vehicle miles traveled
- Vehicle hours traveled

In each distribution, weighted trips were used. The weights developed previously by MAG depend upon the residential location of the household from which the trip record was taken. The weights reflect household sampling rates, but do not take into account the under-reporting of household trips. The percentage of trips in the A.M. and P.M. peak periods were determined by developing a frequency distribution of trips by trip purpose and by hour of the day, and summing the hourly percentages for each trip purpose in the two peak periods. Table 1 presents the results of those frequency distributions.

To obtain the distribution of vehicle miles traveled, each weighted trip was multiplied by its distance. Likewise the distribution of vehicle hours of travel was determined using weighted trips multiplied by their peak-hour travel time required to make the trip as reflected in a peak-hour skimmed tree developed from the MAGTPO 1980 base network.

Table 1

COMPARISON OF ALTERNATIVE PEAK PERIOD TRIP FACTORS

Trip Type	A.M. Trips	A.M. VHT	A.M. VMT	P.M. Trips	P.M. VHT	P.M. VMT
Production to Attraction						
HBW	0.329	0.340	0.344	0.033	0.030	0.029
HBNW*	0.067	0.082	0.086	0.086	0.079	0.076
HBShop		0.021	0.022		0.102	0.102
HBO		0.066	0.071		0.072	0.068
HBSchool		0.335	0.329		0.056	0.061
Ext-Int	0.056			0.119		
Airport	0.041			0.113		
Attraction to Production						
HBW	0.011	0.009	0.008	0.285	0.300	0.303
HBNW*	0.009	0.008	0.007	0.128	0.085	0.133
HBShop		0.003	0.002		0.172	0.183
HBO		0.010	0.009		0.117	0.119
HBSchool		0.007	0.008		0.107	0.102
Ext-Int	0.077			0.100		
Airport	0.089			0.031		
NHB Total	0.051	0.055	0.057	0.201	0.225	0.231
External-External	0.131			0.205		
Total	0.152	0.179	0.197	0.242	0.243	0.266

Entries in the table represent the daily percentage of trips for the specific trip purpose and direction that occur in the three-hour peak period indicated (A.M., 6 to 9, or P.M., 3 to 6). The value for HBNW is the weighted average of the values for HBShop, HBO, and HBSchool.

The distribution based on trips was used to produce a three-hour assignment to the 1980 network and a comparison was made with three-hour counts for a sample of links. The comparison indicated an under-prediction of trips and VMT by about nine percent. Examination of the effects of using the VMT and VHT based distributions rather than the trip-based distribution indicated that the VHT distribution would not appreciably affect the P.M. peak-hour assignment but the VMT-based distribution would increase the assigned VMT total by about ten percent. Because a more direct comparison was not available with which to validate either of the two distributions, on the basis of the comparison described above, the VMT-based distribution was recommended. The use of the VMT-based distribution is certainly appropriate on a theoretical basis because the effect of a trip on the highway network is likely to be proportional to its length: a trip that is twice as long is likely to have twice the impact on the network.

A second issue which affects the overall peaking factor for the full trip table is the relative weighting given to each trip type. Previous research work by MAG has revealed that use of the un-weighted trip tables produces an under-estimate of VMT in the twenty-four hour assignment. On the assumption that this under-estimate is due mainly to commercial truck trips (for which no survey data are available) and non-home-based auto trips, the correction has been made in the past by expanding only the NHB trips. Fortunately, several new sources of data on VMT by time of day have recently become available and these data have been used to prepare an alternative weighting of the trip purposes to eliminate the short-fall in the twenty-four hour assignment.

The VMT factors presented in Table 2 represent modifications of those shown in Table 1. The original factors were modified to ensure that the vehicle miles traveled (VMT) obtained by expanding base-year data as reported in the travel surveys would match target values of VMT. The steps used in this modification process were the following:

(1) Total VMT. The total VMT reported in the home interview survey (HIS), classified by time period and trip purpose, is summarized in Table 3.

(2) Target Total VMT. In previous modeling work done by MAGTPO, it was found that total daily VMT as measured by link counts could be matched when the following purpose-based under-reporting factors were used:

- HBW - 1.0
- HBNW - 1.0
- NHB - 2.9

These factors, when applied to the totals given in Table 2, imply a region-wide total daily unweighted VMT for survey respondents of 236,652. Although the goal was to obtain better estimates of under-reporting factors by trip purpose, this target total daily VMT was accepted as a control total to be provided by applying the new factors.

(3) Target VMT by Time Period. From work done by MAGTPO using link counts the following daily pattern of VMT was obtained:

- A.M. peak - 17.4 percent of daily VMT
- P.M. peak - 23.3 percent of daily VMT
- Off peak - 59.3 percent of daily VMT

When these percentages are applied to the target level of daily VMT, the following targets by time period are obtained:

- A.M. peak - 41,177.4
- P.M. peak - 55,139.9
- Off-peak - 140,334.6

Table 2

FINAL PEAK PERIOD FACTORS BY TRIP PURPOSE

Trip Type	Time Period			
	A.M. Peak	P.M. Peak	Offpeak	Daily
Production to Attraction				
Home-based work (HBW)	0.370	0.029	0.663	1.034
Home-based non-work (HBNW)	0.147	0.111	1.413	1.648
External-Internal	0.056	0.119	0.825	1.000
Airport	0.041	0.113	0.846	1.000
Attraction to Production				
Home-based work (HBW)	0.009	0.303	0.729	1.034
Home-based non-work (HBNW)	0.012	0.194	1.450	1.648
External-Internal	0.077	0.100	0.823	1.000
Airport	0.089	0.031	0.880	1.000
Non-Home-Based (NHB) Total*				
Survey trips	0.098	0.337	1.201	1.648
Expanded trips	0.034	0.116	0.414	0.568
External-External	0.131	0.205	0.664	1.000

*When peak-period factors are applied to unweighted survey trips, factors for the <u>surveyed trips</u> must be used. When applying factors to trip tables developed using the standard MAGTPO trip generation method (which applies an under-reporting factor of 2.9), the <u>expanded trip</u> factors must be used.

Table 3

VEHICLE-MILES OF TRAVEL REPORTED IN THE HOME INTERVIEW SURVEY, BY TIME PERIOD AND TRIP PURPOSE

Time Period	Trip Purpose: Home-Based Work (HBW)	Home-Based Non-Work (HBNW)	Non-Home Based (NHB)	Total
A.M. Peak	25,733.9	5,922.7	1,968.2	33,624.8
P.M. Peak	24,280.9	13,143.0	7,995.4	45,419.3
Off-Peak	23,026.3	44,094.1	24,674.7	91,795.1
Daily	73,041.1	63,159.8	34,638.3	170,839.2

(4) <u>Under-Reporting Factors by Trip Purpose.</u> New factors--f(HBW), f(HBNW) and f(NHB)--were desired, representing the implied under-reporting in the HIS. By applying these factors to the VMT totals by time period and purpose (Table 3) and summing over all trip purposes, the target VMT values in 3) should be obtained. Factors meeting this requirement can be found by minimizing the squared errors from each equation.

Constraints must be placed on the variables in this minimization problem in order to get a reasonable set of factors. Those selected for use were the following:

- all factors $\geq$ 1
- f(HBNW) $\geq$ f(HBW)
- f(NHB) $\geq$ f(HBNW)

The daily equation above was aso considered as a constraint, to ensure the exact prediction of daily VMT.

Quadratic programming procedurs can be used to solve the system of equations described above. To state the quadratic programming problem mathematically, it is necessary to begin with equations representing the desired VMT summations described above:

A.M. peak: $25{,}733.9\ f(HBW) + 5{,}922.7\ f(HBNW) + 1{,}968.2\ f(NHB) = 41{,}177.4$

P.M. peak: $24{,}280.9\ f(HBW) + 13{,}143.0\ f(HBNW) + 7{,}995.4\ f(NHB) = 55{,}139.9$

Off-peak: $23{,}026.3\ f(HBW) + 44{,}094.1\ f(HBNW) + 24{,}674.7\ f(NHB) = 140{,}334.6$

Daily: $73{,}041.1\ f(HBW) + 63{,}159.8\ f(HBNW) + 34{,}638.3\ f(NHB) = 236{,}652.0$

To simplify these equations, they can be normalized by dividing each by its right hand side:

A.M. peak: $0.6250\ f(HBW) + 0.1438\ f(HBNW) + 0.0478\ f(NHB) = 1$

P.M. peak: $0.4404\ f(HBW) + 0.2384\ f(HBNW) + 0.1450\ f(NHB) = 1$

Off-peak: $0.1641\ f(HBW) + 0.3142\ f(HBNW) + 0.1758\ f(NHB) = 1$

Daily: $0.3086\ f(HBW) + 0.2669\ f(HBNW) + 0.1464\ f(NHB) = 1$

Furthermore, recognizing that it will not be possible to find an exact solution to these four equations, an equation-specific error term is added to the first three equations:

A.M. peak: $0.6250\ f(HBW) + 0.1438\ f(HBNW) + 0.0478\ f(NHB) + e(AM) = 1$

P.M. peak: $0.4404\ f(HBW) + 0.2384\ f(HBNW) + 0.1450\ f(NHB) + e(PM) = 1$

Off-peak: $0.1641\ f(HBW) + 0.3142\ f(HBNW) + 0.1758\ f(NHB) + e(OP) = 1$

No error term is added to the daily equation to ensure that daily VMT will be replicated exactly by the new expansion factors.

An optimum set of factors can be defined as ones which minimize the sum of the squares of the three error variables subject to the constraints described above. The necessity to square the error terms leads to a nonlinear minimization problem, but one which is quadratic in form.

Using equations and variables defined above, the quadratic programming problem can be stated mathematically:

Minimize: $e(AM)^2 + e(PM)^2 + e(OP)^2$

subject to:

$$f(HBW) \geq 1$$
$$f(HBNW) \geq f(HBW)$$
$$f(NHB) \geq f(HBNW)$$

$$0.3086\ f(HBW) + 0.2669\ f(HBNW) + 0.1464\ f(NHB) = 1$$

The solution is thus:

$$f(HBW) = 1.0337$$
$$f(HBNW) = 1.6477$$
$$f(NHB) = 1.6477$$

The corresponding error variables are:

$$e(AM) = +0.0382$$
$$e(PM) = -0.0870$$
$$e(OP) = +0.0230$$

Although these factors replicate daily VMT, due to the constraints, they do not replicate VMT by time period. However, they can be adjusted using the following additional factors by time period:

- A.M. peak = k(AM) = 1.0397
- Off-peak = k(OP) = 1.0235

These factors are related to the error variables in the following way:

$$k(AM) = 1/[1 - e(AM)]$$

$$k(OP) = 1/[1 - e(OP)]$$

In the case of P.M. peak trips, this approach fails because the product of the required k factor (0.920) and f(HBW) (1.0337) is 0.951, no longer a logical under-reporting factor. In this case, therefore, the total HBW P.M. peak factor was set to 1.00, its logical minimum, and the P.M. peak factors for the remaining purposes was set to 1.4602, the value required to match the target developed above.

The final under-reporting factors presented in Table 4 represent the products of f and k factors for A.M. peak and offpeak trips, the derived f factors for daily trips, and the specially developed factors for P.M. peak trips. When these factors are multiplied by the HIS VMT factors in Table 1, peak-period trip factors representing both time-of-day patterns and adjustments for under-reporting are obtained. These are the values presented in Table 2 above.

These factors can be applied directly to the MAGTPO trip tables for any existing or future scenario using UMATRIX. Production-to-attraction factors are applied to the existing 24-hour trip tables. Attraction-to-production factors are applied to transposed trip tables, in which each I-to-J element is "swapped" with the corresponding J-to-I element. Origin-to-destination factors are applied directly to trip tables which are in origin-to-destination format.

Table 4

UNDER-REPORTING FACTORS BY TIME PERIOD AND TRIP PURPOSE

Time Period	Trip Purpose HBW	HBNW	NHB
A.M. peak	1.0748	1.7132	1.7132
P.M. peak	1.0000	1.4602	1.4602
Offpeak	1.0580	1.6865	1.6865
Daily	1.0337	1.6477	1.6477

3.0 MODELING OF PEAK-SPREADING AS A FACILITY BECOMES CONGESTED

3.1 ESTIMATION OF PEAK SPREADING FUNCTION

The most significant advancement in peak-hour modeling and the primary focus of this project came in the development of a model to represent the effect of peak-period congestion on the temporal distribution of demand during that period. It has long been recognized that as a facility becomes congested, some trip makers will adjust the time at which they travel to avoid the congestion and that this leads to some flattening of the peak period. However, this behavior has not been captured in the common UTPS travel forecasting process used by most planning agencies.

In this part of the research, historical data from forty-nine freeway and arterial facilities in Arizona, California, and Texas were used to estimate a functional relationship between the peak-hour factor (the ratio of the volume of traffic in the single highest hour to the volume during the three highest hours) and the V/C ratio during the three-hour peak.

The functional form chosen for the peak spreading model was:

$$P = 1/3 + a\, e^{b(V/C)} ,$$

where

P = the ratio of peak-hour volume to peak-period (three-hour) volume,

V/C = the volume/capacity ratio for the three-hour period, and

a,b = model parameters.

The functional form was chosen because it has the general shape illustrated in Figure 2 and the following desirable characteristics:

- it always has a value of one-third or greater;
- P approaches one-third for large values of V/C; and
- valid values of P are defined for values of V/C greater than one.

The parameters in this equation were estimated using ordinary least squares regression for the transformed equation:

$$\ln (P - 1/3) = \ln a + b(V/C)$$

or

$$\ln (P - 1/3) = g + b(V/C)$$

where

$$g = \ln a \quad .$$

The regression model was estimated using data from the forty-five corridors for which historical data were available. The parameters **g** and **b** in the model were estimated for each corridor for the peak direction using data from both the A.M. and P.M. peak periods. The results are illustrated in Tables 5 and 6. Because the model was to be recalibrated for use in Phoenix by adjusting the value of g, the primary focus in this part of the analysis was on the estimates of b.

Figure 2

THEORETICAL RELATIONSHIP BETWEEN PEAKING FACTOR AND VOLUME/CAPACITY RATIO

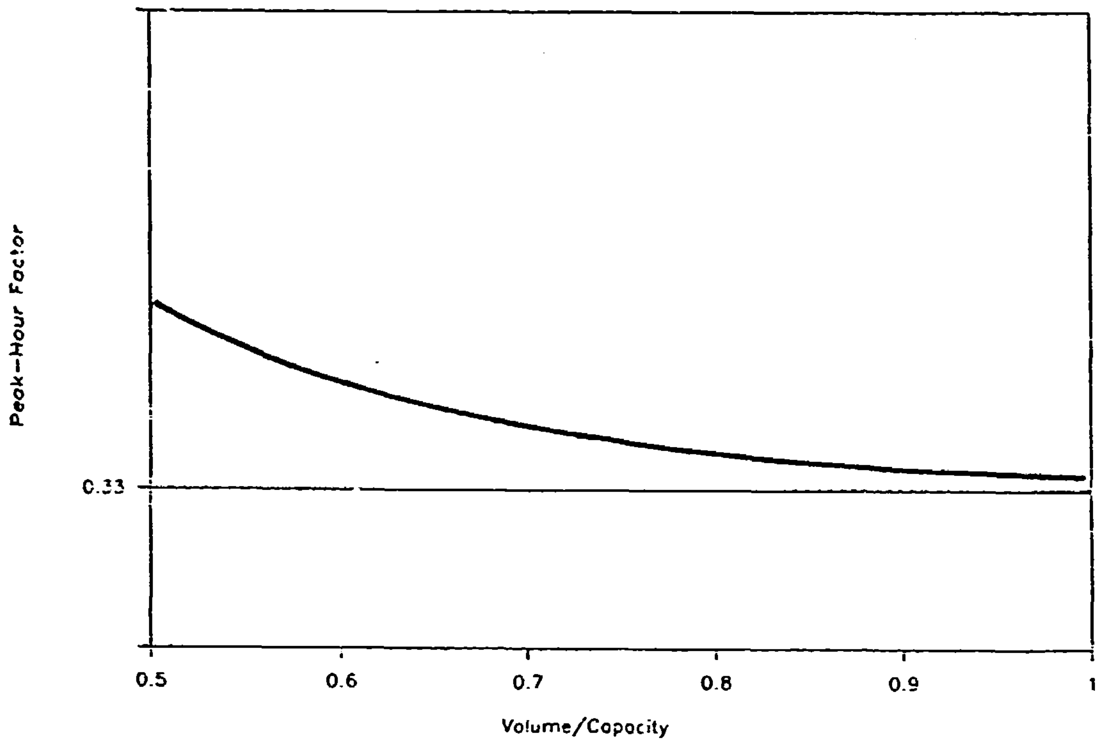


Table 5

FACILITY-SPECIFIC RESULTS OF REGRESSION ANALYSIS
OF PEAKING FACTORS - FREEWAYS

CITY	CORRIDOR	b	g	# OBS	R-SQRD	ST ERR b	T-STAT b	V/C Range Low	V/C Range High
ARIZONA									
PHOENIX	I-10 & 49TH ST.	-2.19	-1.14	18	0.33	0.77	-2.83	.27	.41
CALIFORNIA									
BRENER PK	RT. 91 & HOLDER	-2.14	-2.60	8	0.05	3.65	-0.59	.67	.90
CASTAIC	I-5 AT RT. 126 W	-16.43	-1.38	7	0.27	12.16	-1.35	.16	.22
LOS GATOS	HWY 17 AT RT. 9	-8.66	3.26	10	0.65	2.24	-3.87	.73	.85
OAKLAND	HIGHWAY 24	-2.08	-1.08	8	0.18	1.81	-1.15	.82	1.17
PLEASANTON	I-580	-1.15	-2.61	10	0.43	0.47	-2.46	.60	.87
SAN DIEGO	I-5 AT ENCINADOS	-1.11	-2.60	9	0.06	1.71	-0.65	.42	.74
SAN FRAN.	GOLDEN GATE BR	-3.97	-0.46	4	0.09	8.86	-0.45	.57	.60
SAN FRAN.	BAY BRIDGE	0.92	-5.49	10	0.00	5.70	0.16	.912	1.04
SAN LUIS OBISPO	HWY 101 & LOS OSO RD	-5.17	-1.76	10	0.19	3.76	-1.37	.26	.37
SAN RAMON	HWY 580 & HWY 680	-1.85	-2.58	8	0.23	1.37	-1.35	.43	.66
SANTA ROSA	HWY 101 AT RT.12	-3.17	-1.15	10	0.38	1.44	-2.20	.65	.94
WILMINGTON	RT. 110 AT C ST	0.41	-3.22	6	0.01	2.42	0.17	.50	.61
TEXAS									
ARLINGTON	I-30	-2.18	-1.00	8	0.32	1.29	-1.69	.53	.78
AUSTIN	US-183	-1.14	-1.97	22	0.03	1.38	-0.83	.12	.36
AUSTIN	I-35	-2.48	-0.76	8	0.57	0.88	-2.82	.45	.87
AUSTIN	I-35	-1.31	-2.69	22	0.08	1.02	-1.28	.17	.56
DALLAS	I-635	-5.10	0.84	22	0.57	1.00	-5.11	.62	1.05
DALLAS	I-30	-3.22	-0.62	22	0.10	2.13	-1.51	.75	.94
DALLAS	I-35E	-1.58	-1.44	22	0.34	0.50	-3.18	.71	.89
DALLAS	US-75	-0.29	-3.00	22	0.00	1.69	-0.17	.66	.93
DALLAS	I-35E	-2.73	-1.73	22	0.12	1.63	-1.68	.47	.84
HOUSTON	I-45	-0.48	-3.12	22	0.09	0.34	-1.41	.50	1.03
HOUSTON	I-610	-4.78	0.59	20	0.35	1.53	-3.12	.55	.81
HOUSTON	US-59	-0.83	-2.57	22	0.34	0.26	-3.19	.31	.99
HOUSTON	US-59	-3.18	-0.83	18	0.33	1.13	-2.82	.69	.94
HOUSTON	I-10	-2.46	-1.03	22	0.20	1.09	-2.26	.70	.94
HOUSTON	I-610	-2.75	-1.25	22	0.19	1.28	-2.15	.32	.63
SAN ANTON.	I-37	-2.44	-1.34	20	0.26	0.96	-2.53	.30	.66
SAN ANTON.	I-410	-1.61	-1.62	18	0.15	0.94	-1.71	.25	.73
SAN ANTON.	US-281	1.04	-3.17	16	0.06	1.11	0.94	.26	.70
SAN ANTON.	I-410	-2.03	-1.29	20	0.37	0.62	-3.25	.48	1.00

REGRESSION EQUATION: LN(peak vol/3-hr vol - 1/3)= g + b(V/C)

Table 6

FACILITY-SPECIFIC RESULTS OF REGRESSION ANALYSIS
OF PEAKING FACTORS - ARTERIALS

LOCATION	CORRIDOR	b	g	# OBS	R-SQRD	ST ERR b	T-STAT b	V/C Ratio Low	V/C Ratio High
ARIZONA									
PHOENIX	UNIVERSITY AT STANDAGE	-8.35	-1.80	21	0.31	2.86	-2.92	0.18	0.35
PHOENIX	BROADWAY AT STAPLEY	-6.84	-2.17	18	0.26	2.86	-2.39	0.18	0.32
PHOENIX	SCOTTSDALE AT THOMAS	15.82	1.45	10	0.50	5.60	-2.82	0.27	0.41
PHOENIX	US-60 AT CURRY	-3.41	-1.13	18	0.17	1.89	-1.81	0.30	0.59
TUCSON	WILMOT AT 22ND ST-SB	-1.38	-2.46	5	0.27	1.32	-1.04	0.43	0.74
TUCSON	WILMOT AT BROADWAY-SB	8.22	-10.56	3	0.99	0.81	10.15	0.69	0.82
TUCSON	WILMOT AT BROADWAY-WB	1.45	-3.62	5	0.19	1.70	0.85	0.50	0.68
TUCSON	SPEEDWAY AT CAMBELL-WB	-6.12	-0.05	3	0.71	3.90	-1.57	0.72	0.92
TUCSON	WILMOT AT BROADWAY-NB	-0.64	-4.56	3	0.00	6.66	-0.04	0.43	0.55
TUCSON	WILMOT AT 22ND ST-EB	-0.76	-2.92	3	0.93	0.20	-3.74	0.32	0.69
TUCSON	WILMOT AT SPEEDWAY-WB	-1.08	-2.28	3	0.08	3.59	-0.30	0.35	0.45
TUCSON	WILMOT AT SPEEDWAY-SB	-6.05	-0.51	5	0.43	4.05	-1.49	0.45	0.61
CALIFORNIA									
LOS ANG.	VENTURA AT SEPULVEDA	-2.31	-1.68	6	0.65	0.84	-2.75	0.54	0.85
LOS ANG.	WILSHIRE AT VETERAN	0.72	-4.49	10	0.03	1.53	0.47	0.83	1.06
LOS ANG.	WILSHIRE AT SEPULVEDA	-2.53	-1.65	6	0.16	2.93	-0.86	0.66	0.94
LOS ANG.	WILSHIRE AT WESTWOOD	2.72	-6.41	6	0.06	5.21	0.52	0.57	0.78

REGRESSION EQUATION: $\ln(\text{peak vol}/\text{3-hr vol} - 1/3) = g + b(V/C)$

The existence of the peak-spreading phenomenon is clearly demonstrated for freeway facilities by the results in Table 5. One would expect the peak-spreading to occur only under congested conditions and so the regression analysis was performed using only peak direction travel. Of the thirty-two freeway corridors included in the analysis, nineteen had V/C ratios in excess of .75 at some time during the period observed. Of these nineteen corridors, eighteen had estimated values of b with the correct sign (negative) and over half (eleven) had t-statistics greater than two (reflecting statistical significance at roughly a ninety-five percent confidence level). Three additional corridors had t-statistics between 1.5 and 2.0, and two between 1.0 and 1.5. The only corridor for which the estimated coefficient had the incorrect sign (positive) was the Bay Bridge in the San Francisco Bay Area. This particular corridor, however, reflects the need for close attention to the variation in V/C ratio observed. The range in variation for the Bay Bridge was only .92-1.00, indicating highly congested conditions throughout the period of observation. When both peak and non-peak directions were used for the Bay Bridge, the variation in the V/C ratio was .61 to 1.00 and the estimated coefficient (b) was negative and significantly different than zero at a ninety percent confidence level.

Thirteen freeway corridors did not have V/C ratios in excess of .75, and only three of these corridors produced coefficient estimates with t-statistics of two or greater. This provided support for the hypothesis that peak-spreading was significant only under congested conditions. For the freeway corridors with values of b significantly different than zero at a ninety-five percent confidence level, the range of values was -0.83 to -8.66 with a mean value of -2.96. Among the arterial corridors the range of values for the corridors with values of b significantly different than zero was -0.76 to -15.82; however, only one corridor had values of V/C that exceeded .75 for the three-hour period, reflecting the presence of congestion. The value of b for that corridor, Ventura Boulevard in Los Angeles, was negative and significantly different than zero at a ninety-five percent confidence level.

The average value of b for each facility type was estimated by aggregating the data from the individual corridors if the individual corridor regression produced results that were of the correct sign and significantly different than zero. Tables 7, 8 and 9 present the results of the aggregate analysis. For each facility type, freeways and arterials, three aggregations were tried:

- peak direction for all corridors;
- peak direction only for corridors with a t-statistic for b of greater than 1.5; and
- peak direction only for corridors with a t-statistic for b of greater than 2.0.

The aggregate analysis for the freeway corridors indicated that the exclusion of the corridors with t statistics for b less than 1.5 significantly improves the explanatory power of the model as reflected in the R^2 value. It is also worth noting that the aggregate estimate of b does not vary significantly between using screening criteria of $t > 1.5$ or $t > 2$.

Table 7

AGGREGATE RESULTS OF REGRESSION ANALYSIS
OF PEAKING FACTORS - FREEWAYS

X: 3-HR VOL/3-HR CAP
Y: LN(PEAK VOL/3-HR VOL - 1/3)

REGRESSION OF PEAK DIRECTION IN ALL CORRIDORS

Regression Output:

Constant	-2.67240
Std Err of Y Est	0.70048
R Squared	0.05246
No. of Observations	518
Degrees of Freedom	516
X Coefficient(s)	-0.64590
Std Err of Coef.	0.12084

REGRESSION OF PEAK DIRECTION WITH t > 1.5

Regression Output:

Constant	-1.56509
Std Err of Y Est	0.53169
R Squared	0.28750
No. of Observations	314
Degrees of Freedom	312
X Coefficient(s)	-2.06169
Std Err of Coef.	0.18375

REGRESSION OF PEAK DIRECTION WITH t > 2

Regression Output:

Constant	-1.50437
Std Err of Y Est	0.49197
R Squared	0.31418
No. of Observations	244
Degrees of Freedom	242
X Coefficient(s)	-2.10689
Std Err of Coef.	0.20010

Table 8

AGGREGATE RESULTS OF REGRESSION ANALYSIS
OF PEAKING FACTORS BY NUMBR OF LANES - FREEWAYS

X: 3-HR VOL/3-HR CAP
Y: LN(PEAK VOL/3-HR VOL - 1/3)

REGRESSION OF PEAK DIRECTION
WITH t > 1.5

5 LANES
Regression Outpu

Constant	-1.53954
Std Err of Y Est	0.56399
R Squared	0.23466
No. of Observations	55
Degrees of Freedom	53
X Coefficient(s)	-2.54409
Std Err of Coef.	0.63111

3 LANES
Regression Output:

Constant	-1.41794
Std Err of Y Est	0.47875
R Squared	0.39714
No. of Observation	74
Degrees of Freedom	72
X Coefficient(s)	-2.06484
Std Err of Coef.	0.29982

4 LANES
Regression Output:

Constant	-0.84532
Std Err of Y Est	0.48774
R Squared	0.39444
No. of Observations	135
Degrees of Freedom	133
X Coefficient(s)	-2.86216
Std Err of Coef.	0.30751

2 LANES
Regression Output:

Constant	-1.84972
Std Err of Y Est	0.50168
R Squared	0.32359
No. of Observations	50
Degrees of Freedom	48
X Coefficient(s)	-1.95146
Std Err of Coef.	0.40724

4 OR MORE LANES
Regression Output:

Constant	-1.53674
Std Err of Y Est	0.54417
R Squared	0.25297
No. of Observations	189
Degrees of Freedom	187
X Coefficient(s)	-2.10823
Std Err of Coef.	0.26493

3 OR LESS LANES
Regression Output:

Constant	-1.59
Std Err of Y Est	0.51
R Squared	0.34
No. of Observations	124.00
Degrees of Freedom	122.00
X Coefficient(s)	-2.02
Std Err of Coef.	0.26

Table 9

AGGREGATE RESULTS OF REGRESSION ANALYSIS
OF PEAKING FACTORS - ARTERIALS

X: 3-HR VOL/3-HR CAP
Y: LN(PEAK VOL/3-HR VOL - 1/3)

REGRESSION OF PEAK DIRECTION
IN ALL CORRIDORS

Regression Output:	
Constant	-3.46174
Std Err of Y Est	0.83253
R Squared	0.01159
No. of Observations	120
Degrees of Freedom	118
X Coefficient(s)	-0.39323
Std Err of Coef.	0.33426

REGRESSION OF PEAK DIRECTION
WITH t > 1.5

Regression Output:	
Constant	-3.61410
Std Err of Y Est	0.88601
R Squared	0.00014
No. of Observations	77
Degrees of Freedom	75
X Coefficient(s)	0.05994
Std Err of Coef.	0.58513

REGRESSION OF PEAK DIRECTION
WITH t > 2

Regression Output:	
Constant	-3.87796
Std Err of Y Est	0.71081
R Squared	0.00351
No. of Observations	57
Degrees of Freedom	55
X Coefficient(s)	0.27461
Std Err of Coef.	0.62411

Differences in the value of the aggregate freeway regression for freeways by number of lanes were also explored. Table 8 presents the results of regressions segmented by number of lanes. Each regression produces values of **b** that are significantly different than zero and the regression results together reflect a general trend of decreasing **b** (more negative) with increasing number of lanes, the only exception being the change from four lanes to five lanes. The regression results, by number of lanes, for the freeway data are presented graphically in Figure 3. Grouping of the observations with four and five lanes and grouping those with two and three lanes produces the same pattern of decreasing **b** with increasing number of lanes but the difference between the two values of **b** is quite small. Based on the results of these regression analyses, the following values of **b** are recommended for freeways and expressways:

4 or more lanes	b = -2.11
2 or 3 lanes	b = -2.03

As reflected in Table 9, the results of the aggregate analysis for the arterial corridors was of limited usefulness primarily because of the lack of data from corridors with high V/C ratios. None of the three regressions produced values of **b** that were of the correct sign and significantly different than zero at a ninety-five percent confidence level. Because of the lack of useful aggregate results, the results from the Ventura Boulevard corridor in Los Angeles are recommended to represent arterial corridors in the MAG models. The value of **b** from this corridor was -2.31. A plot of the regression results for this corridor versus the actual data is presented in Figure 4.

A simple sensitivity analysis was performed on the values of **b** chosen. It was found that for the values of **a** estimated specifically for Phoenix using observed data, a ten percent increase in the value of **b** would produce an increase in P of roughly one percent for a V/C ratio of .9 .

Figure 3

PLOT OF REGRESSION ANALYSIS OF PEAKING FACTOR

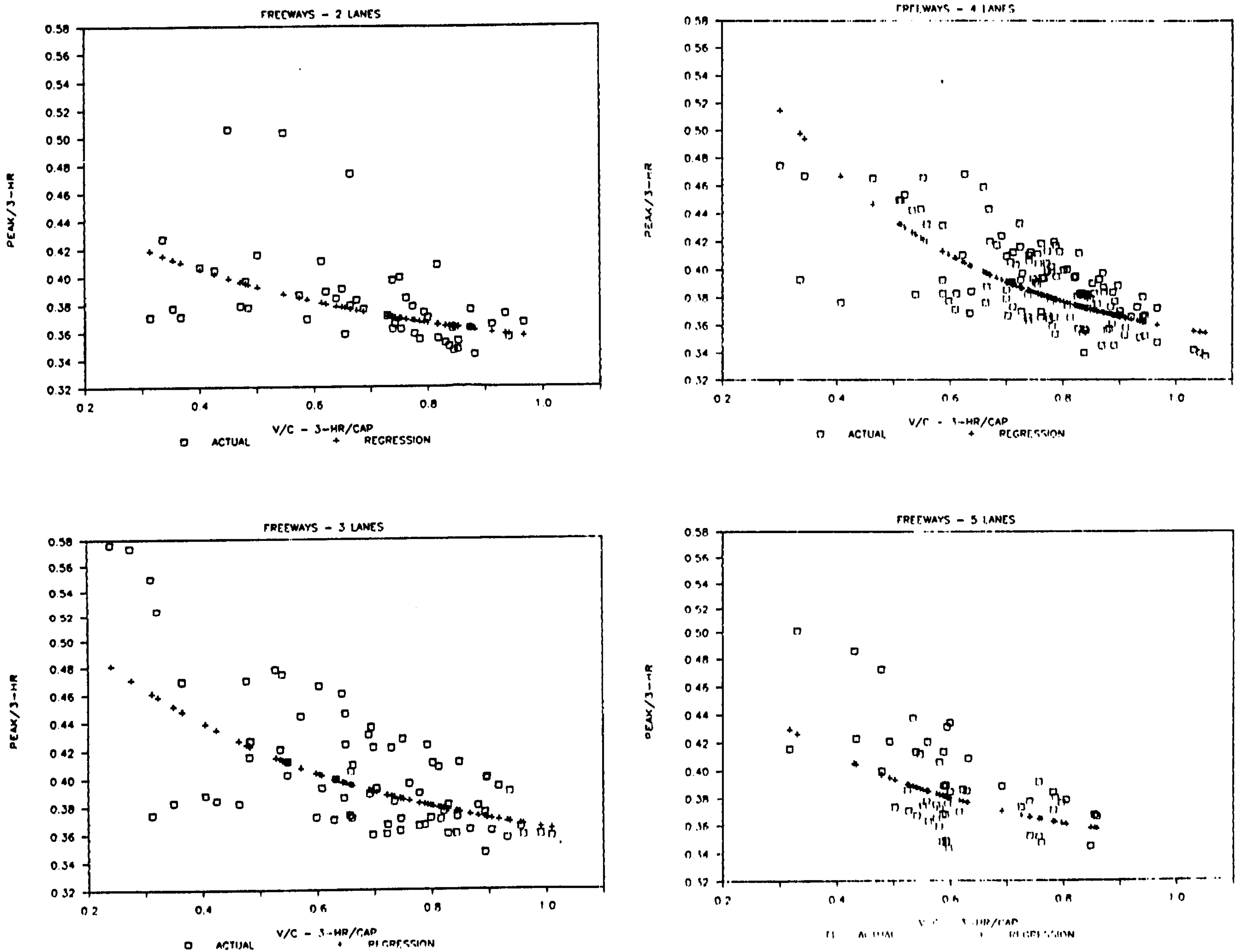
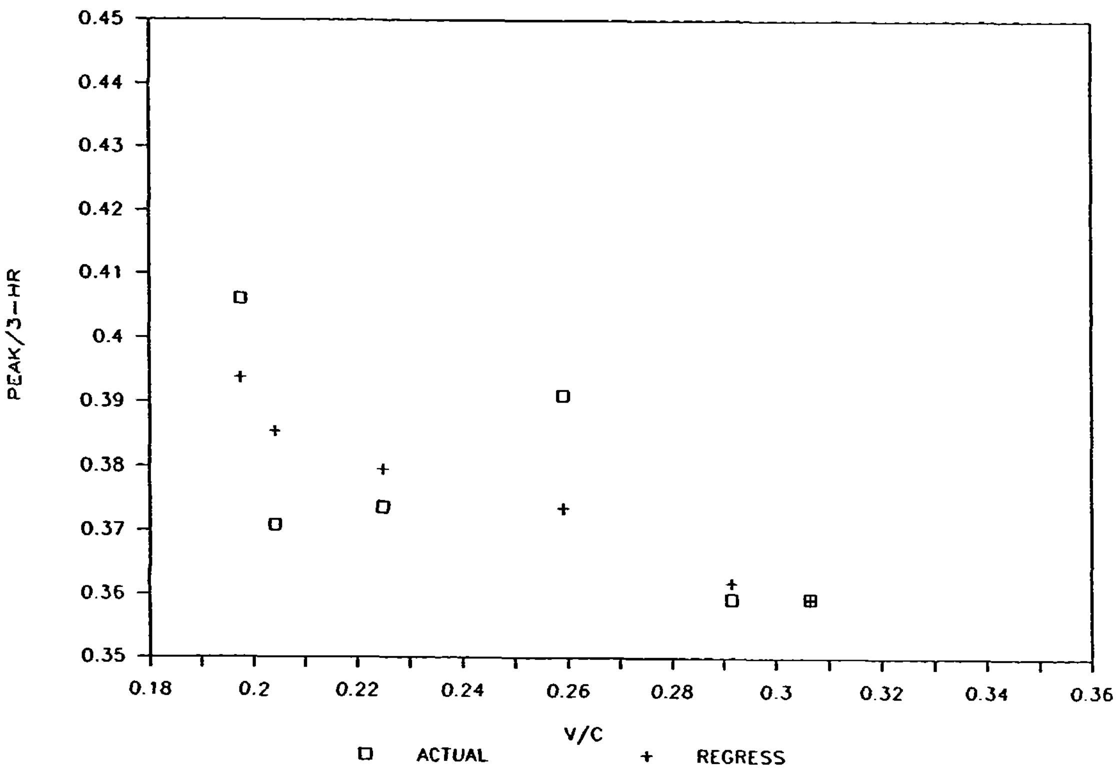


FIGURE 4

PLOT OF REGRESSION ANALYSIS OF PEAKING FACTORS - VENTURA BOULEVARD



To more closely reflect the current conditions (1985 and 1986) in Phoenix, the model was recalibrated for different facility type and area type combinations in the Phoenix network using observed 1985 data. The calibration is performed using the relationship

$$a_1 = (P^o - 1/3)/e^{b_f (V/C)^o} ,$$

where

- P^o = the observed value of the peaking factor for the area type-facility type combination;
- $(V/C)_o$ = the value of the V/C ratio for the area type-facility type combination;
- a_1 = the value of a calibrated to a specific link type; and
- b_f = the value of b previously estimated for the specific facility type under consideration.

The values of P^o and $(V/C)^o$ are the average observed 1985 values for the links in each area type-facility type combination.

An analysis of current peaking factors was performed on 1985 data collected in Phoenix. Traffic counts were available for 517 locations in the metropolitan area. Most locations were two-way facilities and produced count data for two one-way links in the network. In all, 988 links had count data.

An analysis of the current peaking factors and V/C ratios for Phoenix supported the theoretical arguments for the model of peak-spreading; that as facilities become congested, the peaking of traffic is reduced. This was demonstrated by the significantly higher peaking factors in the A.M. period when the average V/C ratio was generally much lower than the P.M. period. The peaking factors were also generally lower in the denser areas where the V/C ratio was also generally higher.

3.2 ALTERNATIVE LINK-VOLUME-SPREADING MODELS

Although the basic link-volume-spreading modeling approach presented above has been retained, a number of expansions and changes have been made for a number of reasons:

- to respond to ADOT's review of the previous memo which suggested some simplifications as well as desires for expanded capabilities;
- to reflect refinements in the data used for model estimation;
- to adapt the implemented models to limitations of the UTPS UROAD highway assignment program.

As implemented, the overall modeling strategy includes three somewhat different approaches to peakhour travel forecasting:

- <u>Three-hour trips/ three-hour volume-spreading:</u> This approach, as outlined above, is based on 3-hour peak period trip tables plus volume spreading to estimate peak-hour volumes and speeds within this peak period. This approach can be used to forecast either A.M. or P.M. peak hour volumes.
- <u>24-hour trips/three-hour volume-spreading:</u> A new approach based on 24-hour (daily) trip tables, link-specific 3-hour to 24-hour volume ratios, and volume spreading within the 3-hour peak period. This approach provides forecasts of peak hour directional volumes for each link which might occur in either the A.M. or P.M. peak period depending on link orientation.
- <u>24-hour trips/24-hour volume-spreading:</u> A new approach based on 24-hour trip tables and volume spreading over the entire 24-hour period. This approach also provides estimates of directional link volumes which represent peaks over the entire day rather than during either A.M. or P.M. peak period.

Each of these approaches is described separately in the subsections which follow.

3.2.1. Model for Three-Hour Trips and Three-Hour Volume Spreading

For this method, the volume-spreading functions applied to all links in existing and future networks have the following form:

$$P_1 = \min\{(\tfrac{1}{3} + a_C e^{b_{ft,n}(V/C)_1}), P_C\max\}$$

where:

P_1 = the ratio of peak-hour volume to peak-period volume on link 1.

$(V/C)_1$ = the ratio of volume to possible capacity* for the 3-hour peak period on link 1.

$b_{ft,n}$ = a parameter specific to facility type and number of lanes, with values shown in Table 10.

a_C = a parameter specific to a given level of possible capacity, with values shown in Table 11.

$P_C\max$ = the maximum value of P_1, specific to a given level of capacity, with values shown in Table 11.

The value of a_C and $P_C\max$ are computed as averages over area types of all links having a unique capacity value. Capacity values themselves are assigned in the MAGTPO analysis system by facility type, area type, and number of lanes. Thus a_C is an average of values such as:

* Possible capacity is the volume of traffic at which there is a transition from level of service E to level of service F for the facility.

Table 10

FACILITY CHARACTERISTICS AND PARAMETER VALUES

Facility Type	Number of Lanes	Value of b: Three-hour Models (3.2.1, 3.2.2)*	Value of b: 24-Hour Model (3.2.3)*
Freeways and expressways	<4	- 2.02	- 3.029
	≥4	- 2.11	- 2.208
All other	Any	- 2.31	- 1.892

*The numbers in parentheses indicate the report sections in which each model is discussed.

Table 11

PARAMETERS OF THREE-HOUR VOLUME-SPREADING MODELS

Facil. Type	Number of Lanes	Area Type	Possible Capacity*	a_c A.M.	a_c P.M.	$P\ max_c$ A.M.	$P\ max_c$ P.M.	X_c
1	1	1-5	1500	0.1117	0.0739	0.3837	0.3551	0.2290
1	2,3	1-4	2156	0.1128	0.0818	0.3735	0.3524	0.2306
1	2,3	5	1733	0.1094	0.0565	0.4063	0.3608	0.2256
1	4+	1-4	2156	0.1193	0.0870	0.3739	0.3524	0.2306
1	4+	5	1733	0.1125	0.0579	0.4070	0.3607	0.2256
2	1	1-2	936	0.1128	0.0818	0.3735	0.3524	0.2306
2	1	3-4	835	0.1128	0.0818	0.3735	0.3524	0.2306
2	1	5	713	0.1094	0.0565	0.4063	0.3608	0.2256
2	2	1-2	887	0.1128	0.0818	0.3735	0.3524	0.2306
2	2	3-4	790	0.1128	0.0818	0.3735	0.3524	0.2306
2	2	5	675	0.1094	0.0565	0.4063	0.3608	0.2256
2	3	1-2	870	0.1128	0.0818	0.3735	0.3524	0.2306
2	3	3-4	785	0.1128	0.0818	0.3735	0.3524	0.2306
2	3	5	663	0.1094	0.0565	0.4063	0.3608	0.2256
2	4+	1-2	842	0.1193	0.0870	0.3739	0.3524	0.2306
2	4+	3-4	767	0.1193	0.0870	0.3739	0.3524	0.2306
2	4+	5	657	0.1125	0.0579	0.4070	0.3608	0.2256
3	1	1-3	453	0.6237	0.6428	0.4808	0.4022	0.2685
3	1+	4-5	231	0.6237	0.6428	0.4808	0.4022	0.2685
3	2	1-3	429	0.6237	0.6428	0.4808	0.4022	0.2685
3	3+	1-3	421	0.6237	0.6428	0.4808	0.4022	0.2685
4	1	1-3	418	0.3506	0.1852	0.4612	0.3668	0.2546
4	1	4-5	375	0.3762	0.3179	0.4547	0.3958	0.2605
4	2	1-3	395	0.3506	0.1852	0.4612	0.3668	0.2546
4	2	4-5	364	0.3762	0.3179	0.4547	0.3950	0.2605
4	3	1-3	388	0.3506	0.1852	0.4612	0.3668	0.2546
4	3	4-5	358	0.3762	0.3179	0.4547	0.3950	0.2605
4	4+	1-3	384	0.3506	0.1852	0.4612	0.3668	0.2546
4	4+	4-5	354	0.3762	0.3179	0.4547	0.3950	0.2605

continued

*Capacity is expressed as vehicles/hour/lane.

Table 11, continued

Facil. Type	Number of Lanes	Area Type	Possible Capacity*	a_c A.M.	a_c P.M.	$P\ max_c$ A.M.	$P\ max_c$ P.M.	X_c
6	1	1-2	787	0.3576	0.1876	0.4439	0.3646	0.2540
6	1	3	702	0.3164	0.1733	0.4593	0.3774	0.2578
6	1	4	661	0.3164	0.1733	0.4593	0.3774	0.2578
6	1	5	337	0.4201	0.4241	0.4513	0.4079	0.2625
6	2	1-2	745	0.3576	0.1876	0.4439	0.3646	0.2540
6	2	3	664	0.3164	0.1733	0.4593	0.3774	0.2578
6	2	4	623	0.3164	0.1733	0.4593	0.3774	0.2578
6	2	5	571	0.4201	0.4241	0.4513	0.4079	0.2625
6	3	1-2	731	0.3576	0.1876	0.4439	0.3646	0.2540
6	3	3	651	0.3164	0.1733	0.4593	0.3774	0.2578
6	3	4	610	0.3164	0.1733	0.4593	0.3774	0.2578
6	3	5	559	0.4201	0.4241	0.4513	0.4079	0.2625
6	4	1-2	724	0.3576	0.1876	0.4439	0.3646	0.2540
6	4	3	645	0.3164	0.1733	0.4593	0.3774	0.2578
6	4	4	604	0.3164	0.1733	0.4593	0.3774	0.2578
6	4	5	553	0.4201	0.4241	0.4513	0.4079	0.2625
6	5	1-2	703	0.3576	0.1876	0.4439	0.3646	0.2540
6	5	3	625	0.3164	0.1733	0.4593	0.3774	0.2578
6	5	4	585	0.3164	0.1733	0.4593	0.3774	0.2578
6	5	5	534	0.4201	0.4241	0.4513	0.4079	0.2625

*Capacity is expressed as vehicles/hour/lane.

$$a_{at,ft,n} = \left(P^{o}_{at,ft} - \frac{1}{3}\right) e^{-b_{ft,n} (V/C)^{o}_{at,ft}}$$

where P^o and $(V/C)^o$ represent observed values in the peak direction for Phoenix by time of day, provided in Table 12.

It was necessary to use capacity-specific values of a rather than ones dependent on area type, facility type, and number of lanes, because the area type and facility type descriptors of each link are not available during a UROAD run, and the available values of P^o and $(V/C)^o$ and Pmax are not specific to the number of lanes. The only relevant link variables which are available during a UROAD run are capacity per lane and number of lanes. However, using these, eleven different values of a can be determined for both A.M. and P.M. 3-hour assignment time periods. Thus, a significant degree of variation remains to reflect differences in link type, area type, and number of lanes.

The function used to compute P_1 includes an upper limit, $P_{C}max$, to avoid unrealistically high ratios of peak hour volume to peak period volume. The values of the one-hour/three-hour peaking factor corresponding to the observed volume-capacity ratio in the non-peak direction, also shown in Table 12, were used to obtain capacity-specific values of this upper limit for both A.M. and P.M. peak periods.

Table 12

AVERAGE OBSERVED THREE-HOUR PEAK PERIOD
VOLUME/CAPACITY RATIOS AND PEAKING FACTORS

		Peak Direction					Non-Peak Direction	
		Volume/ Capacity [Peak $(V/C)^o$]		1-Hour Volume/ 3-Hour Volume [P^o]		3-Hr. Vol./ 24-Hr. Vol. [X^o]	Volume/ Capacity [Offpeak $(V/C)^o$]	
Fac. Type	Area Type	A.M.	P.M.	A.M.	P.M.	P.M.	A.M.	P.M.
1,2	1-4	.6220	.6926	.3654	.3535	.2306	.5111	.7198
	5	.3107	.2900	.3918	.3648	.2256	.2006	.3559
3	1-5	.7085	1.1232	.4547	.3813	.2685	.6242	.9672
4-6	1,2	.5935	.7732	.4241	.3648	.2540	.4439	.7755
	3,4	.4501	.6557	.4452	.3714	.2578	.3987	.5929
	5	.5831	.8865	.4425	.3881	.2625	.5499	.7527

Note that in some cases, the V/C ratio in the off-peak in the non-peak direction is higher than the V/C ratio in the P.M. peak in the peak direction.

Because the three-hour trip table used in this volume-spreading approach is directional--with larger flow rates in the peak flow directions--this method provides estimates of link volumes which vary by direction. The entire flow pattern thus represents either A.M. or P.M. peak conditions, depending on which analysis period is selected. Of the three implemented methods listed previously, only this one has this desirable characteristic.

The factor P_1 can be converted to a weighted average hourly factor (WP_1) for the peak period for estimation of travel speeds and times during assignment if we assume that the two hours in the peak period other than the peak hour have roughly equal volumes. The conversion is:

$$WP_1 = P_1^2 + \frac{(1-P_1)^2}{2}$$

This conversion provides an average volume weighted by the hourly volumes during the peak period. This weighted average hourly volume should lead to a more accurate peak-period assignment by more accurately representing the average conditions during the period.

3.2.2 Model for 24-Hour Trips and Three-Hour Volume Spreading

In this method, rather than applying the purpose-based factors discussed in Section 2 to obtain a peak-period trip table, 24-hour trips are assigned without modification. However, as each link is evaluated during the assignment process, its revised travel time is determined using the following fraction of the assigned 24-hour volume:

$$P_l' = X_C * [\min\{(\tfrac{1}{3} + a_C e^{b_{ft,n} X_C (V/C)_l'}), P_C max\}]$$

where

- P_l' = the ratio of maximum daily peak-hour volume to 24-hour volume on link l;
- X_C = the average ratio of 3-hour to 24-hour volume for a given level of link capacity, with values shown in Table 11;
- $(V/C)_l'$ = the ratio of 24-hour volume to possible 3-hour capacity on link l; and

$b_{ft,n}$, a_C, and $P_C max$ are defined in Section 3.2.1 (P.M. values only).

As for variables a_C and $P_C max$, the X_C variables must be specified as functions of capacities rather than area types and facility types. For this variable also, eleven unique values are obtained, based on the observed values in Table 12.

Because the input trip table for this method represents daily travel, which is generally assumed to be non-directional, the method provides estimates of daily maximum link volumes, with no indication of whether these volumes occur in the A.M. or P.M. peak period. Because the P.M. peak period generally produces higher total VMT than the A.M. peak, a_C and b_C parameters for the P.M. period are used rather than A.M. parameters. As for the previous method, estimates of either weighted peak period volumes or peak-hour volumes may be used to estimate changes in travel times.

3.2.3 Model for 24-Hour Trips and 24-Hour Peak-Spreading

As in the previous case, this method involves assigning 24-hour trips. It differs in that volume spreading is assumed to be possible over the entire day rather than only during peak periods. Link-by-link estimates of peak hour volumes are obtained by applying the following fraction to assigned link volumes:

$$P_1' = \min\{(\frac{1}{24} + a_C' e^{b_{ft,n}' (V/C)_1''}), P_C' max\}$$

where

P_1'	= the ratio of maximum daily peak-hour volume to 24-hour volume on link 1.
$(V/C)_1''$	= the ratio of 24-hour volume to 24-hour possible capacity on link 1.
$b_{ft,n}$	= a parameter specific to facility type and number of lanes with values shown in Table 10.
a_C'	= a parameter specific to a given level of possible capacity, with values shown in Table 13.
$P_C max$	= the maximum value of P_1', specific to a given level of capacity, with values shown in Table 13.

As for the three-hour spreading function presented in Section 3.2.1, the values of a_C and P_C' represent averages for sets of facilities with varying facility types and area types, but with common capacity values. The observed values of P^o and $(V/C)^o$ used to obtain component a parameters for averaging are provided in Table 14.

Values of $P_C max$ for the 24-hour volume-spreading function were not available directly from observed data. Instead, these values were estimated after observing that, on average, the $P_C max$ values used in the models discussed in prior sections are six percent greater than the average observed P^o values. This relationship leads to the following equation:

$$P^{o\prime} = 1.06 * P^o \quad ,$$

where

P^o is the observed 24-hour peaking factor in Table 8, and

$P^{o\prime}$ is the corresponding estimated maximum 24-hour peaking factor.

The resulting values of $P^{o\prime}$ were combined by capacity category to obtain the parameters listed in Table 13.

Table 13

PARAMETERS OF THE 24-HOUR VOLUME-SPREADING MODEL

Facility Type	Number of Lanes	Area Type	Possible* Capacity	a'_C	P'_C max
1	1	1-5	1500	0.1119	0.0888
1	2,3	1-4	2156	0.1290	0.0876
1	2,3	5	1733	0.0742	0.0914
1	4+	1-4	2156	0.0945	0.0876
1	4+	5	1733	0.0646	0.0914
2	1	1-2	936	0.1290	0.0876
2	1	3-4	835	0.1290	0.0876
2	1	5	713	0.0742	0.0914
2	2	1-2	887	0.1290	0.0876
2	2	3-4	790	0.1290	0.0876
2	2	5	675	0.0742	0.0914
2	3	1-2	870	0.1290	0.0876
2	3	3-4	785	0.1290	0.0876
2	3	5	663	0.0742	0.0914
2	4+	1-2	842	0.0945	0.0876
2	4+	3-4	767	0.0945	0.0876
2	4+	5	657	0.0646	0.0914
3	1	1-3	453	0.2003	0.1257
3	1+	4-5	231	0.2003	0.1257
3	2	1-3	429	0.2003	0.1257
3	3+	1-3	421	0.2003	0.1257
4	1	1-3	418	0.1318	0.1129
4	1	4-5	375	0.1427	0.1200
4	2	1-3	395	0.1318	0.1129
4	2	4-5	364	0.1427	0.1200
4	3	1-3	388	0.1318	0.1129
4	3	4-5	358	0.1427	0.1200
4	4+	1-3	384	0.1318	0.1129
4	4+	4-5	354	0.1427	0.1200

continued

*Capacity is expressed as vehicles/hour/lane.

Table 13, continued

Facility Type	Number of Lanes	Area Type	Possible* Capacity	a'_C	$P'_{max\,C}$
6	1	1-2	787	0.1324	0.1116
6	1	3	702	0.1285	0.1193
6	1	4	661	0.1285	0.1193
6	1	5	337	0.1531	0.1205
6	2	1-2	745	0.1324	0.1116
6	2	3	664	0.1285	0.1193
6	2	4	623	0.1285	0.1193
6	2	5	571	0.1531	0.1205
6	3	1-2	731	0.1324	0.1116
6	3	3	651	0.1285	0.1193
6	3	4	610	0.1285	0.1193
6	3	5	559	0.1531	0.1205
6	4	1-2	724	0.1324	0.1116
6	4	3	645	0.1285	0.1193
6	4	4	604	0.1285	0.1193
6	4	5	553	0.1531	0.1205
6	5	1-2	703	0.1324	0.1116
6	5	3	625	0.1285	0.1193
6	5	4	585	0.1285	0.1193
6	5	5	534	0.1531	0.1205

*Capacity is expressed as vehicles/hour/lane.

Table 14

AVERAGE OBSERVED 24-HOUR VOLUME/CAPACITY RATIOS AND PEAKING FACTORS

Facility Type	Area Type	Daily Volume/ Capacity o (V/C)	Max. 1-hr. Volume/ 24-hour Volume o P
1,2	1-4	.0826	.3790
	5	.0862	.1686
3	1-5	.1186	.5056
4-6	1,2	.1053	.3872
	3,4	.1126	.3143
	5	.1137	.3988

The volume estimates obtained using this method, like those of the previous method, represent maximum volumes over the entire day. Thus, typically, the volume estimate for the link representing one direction of a two-way facility will correspond to A.M. peak conditions, while the estimate for the opposing direction will correspond to P.M. peak conditions. Because link-volume-spreading is assumed to occur over all of the hours of the day in this method, it is not possible or meaningful to determine a weighted hourly volume, as in the two previous methods.

4.0 MODELING OF PEAK-HOUR SPEEDS

The final step in our analysis has been to re-examine the relationship between speed and volume for different types of facilities with varying capacities. The current MAG procedure produces link-specific assignments and speed estimates in an iterative process. An initial assignment is made using free flow travel speeds on each link to determine travel times on each alternative route. From the initial assignment, a V/C ratio is calculated for each link and a travel speed calculated according to the relationship:

$$S = S_O / [1 + \alpha(V/C)^{\beta}]$$

where

S = predicted speed at specified V/C

S_O = free flow speed

V/C = volume capacity ratio

α and β = model parameters

The new estimate of speed is then used to calculate a new travel time for each link and another assignment is mode. This process continues for the number of times specified by the analyst. The new research in this part of the project has focused on re-evaluating the formula by which speed is calculated as a function of the V/C ratio and the free-flow speed.

Three sources of data were available for this element of the analysis. The first source was a merged data set. The data in that merged data set included travel speeds and traffic counts collected during 1985 and 1986, at different hours of the day and on different types of facilities throughout the system. One serious limitation of this data set is that the traffic counts and the speed measurements were taken independently and not on the same day. The speeds measured were, therefore, not necessarily under the volume conditions represented by the corresponding count. A total of 988 links in the MAG network had counts available but 611 links had both traffic counts and speed measurements.

The second source of data was a combination of traffic speeds and volumes at eight locations along I-17 between Peoria Avenue and McDowell Road. The counts and speed measurements were taken in 1981 and were taken in the south-bound direction in the A.M. period. Counts and speed measurements were available from before and after the installation of ramp metering on I-17 but only the data from after the metering were used in this analysis.

The final source of data for this analysis came from speed and volume measurements taken by ADOT at a single location on I-17 just north of Bethany Home Road during the period from November 4, 1986 to November 6, 1986. The counts from this source were taken at five-minute intervals during a 48-hour period spanning the three days.

The P.M. peak-hour travel speed and V/C data from the merged data set for Phoenix were plotted; these plots are included in Appendix A. While the plot of the freeway observations was generally consistent with the theoretical shape of a speed-volume curve, the plots of the arterial data indicate no discernible pattern. A plot of arterial data by number of lanes also failed to indicate a consistent pattern.

The lack of a discernible pattern in the arterial data is most likely attributable to the fact that the speed data and the volume data were not collected concurrently. While one might expect a reasonably consistent set of conditions to exist on a freeway facility from day to day, the variation in hourly traffic volume on an arterial could be expected to fluctuate much more from day to day.

The relationship in speed-volume function described above was re-estimated on the freeway data from the merged data set and from each of the two other data sets. The relationship was estimated by transforming the expression into a linear form and using ordinary least squares regression with the linear formulation. The expression on which the regression was run was:

$$\ln (S_O/S-1) = \ln \alpha + \beta \ (V/C)$$

Each was estimated using different assumed free-flow speeds. The results of the estimation are presented in Table 15 along with the parameters used by MAG. The significant difference reflects a limitation in using ordinary least squares regression : the method tends to weight more heavily observations with low values of V/C. As illustrated in Figures 5a, 5b, and 5c, the regression line does not adequately represent the reduction of speed at high V/C ratios. Also presented in each figure is a plot of the currently used set of parameters with the free-flow speed of the actual data. To remedy this deficiency of ordinary least squares regression, different values of α and β were tried in the speed-volume function and plotted against the actual data until a reasonable fit of the curve to the data resulted. Figures 6a, 6b, and 6c illustrate the best fitting curves and the corresponding parameters for the three sets of freeway data.

Table 15

RESULTS OF REGRESSION ANALYSIS OF SPEED-VOLUME RELATIONSHIP FOR PHOENIX FREEWAYS

Regression Equation: $\ln (S_o/S-1) = \text{Constant} + \beta * \ln (V/C)$*

	Constant	T-Stat	β	T-Stat	R-Sqrd	# Obs.
ADOT I-17 1985 Data	-2.62	-2.15	0.78	3.90	0.21	59
MAG/ADOT I-17 1981 Data	-1.43	-1.81	2.27	9.08	0.48	93
MAG 1986 Travel Speed Study Data	-2.54	-2.27	2.11	3.30	0.26	33

Currently used model parameters:

Constant = -1.89 $\beta = 6$ for $V/C \leq 2$

Constant = -1.89 $\beta = 4$ for $V/C > 2$

*Capacity (C) is practical capacity, which is seventy-five percent of maximum capacity.

FIGURE 5a

COMPARISON OF SPEED-VOLUME REGRESSION CURVE WITH ACTUAL DATA FROM PHOENIX FREEWAYS -1986 TRAVEL SPEED STUDY DATA FROM I-10 AND I-17

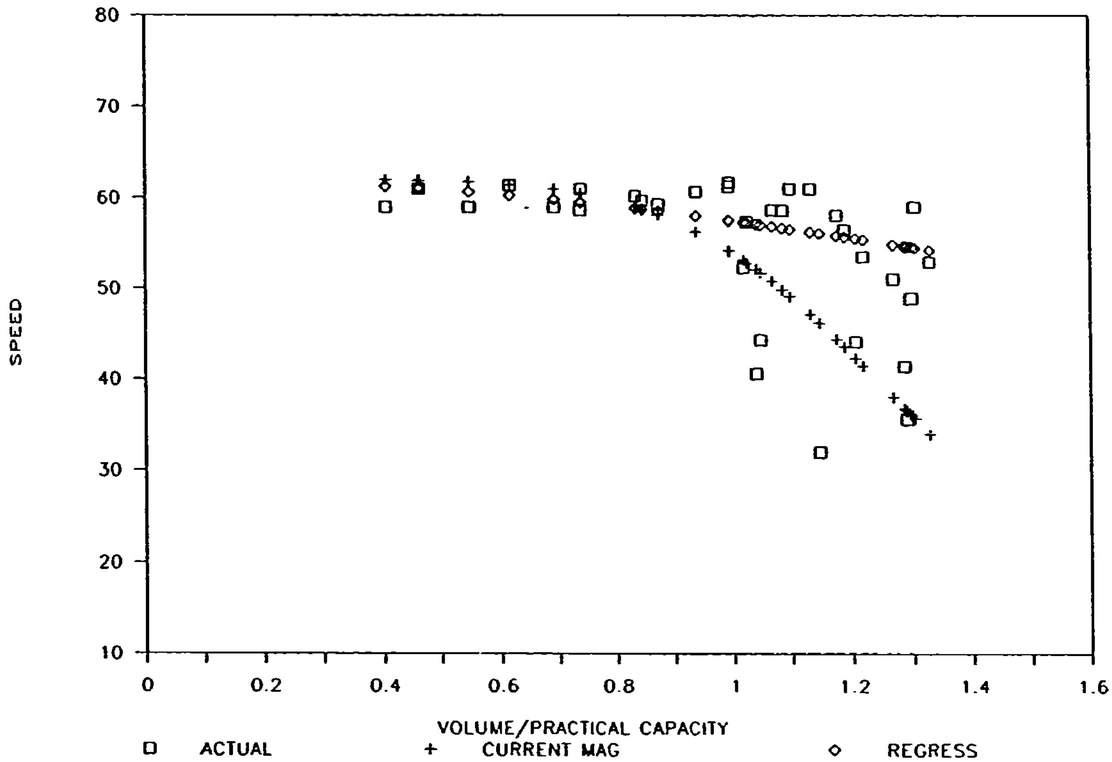


FIGURE 5b

COMPARISON OF SPEED-VOLUME REGRESSION CURVE WITH ACTUAL DATA FROM PHOENIX FREEWAYS - 1986 ADOT DATA FROM I-17

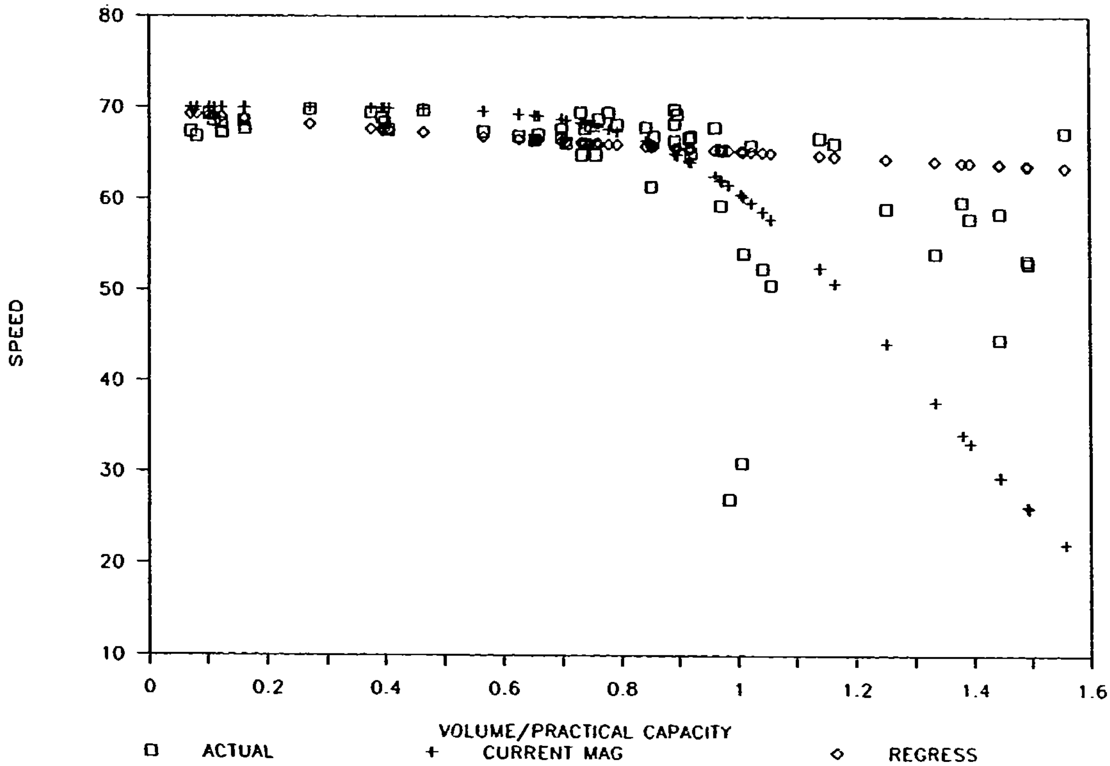


FIGURE 5c

COMPARISON OF SPEED-VOLUME REGRESSION CURVE WITH ACTUAL DATA FROM PHOENIX FREEWAYS - 1981 MAG/ADOT DATA FROM I-17

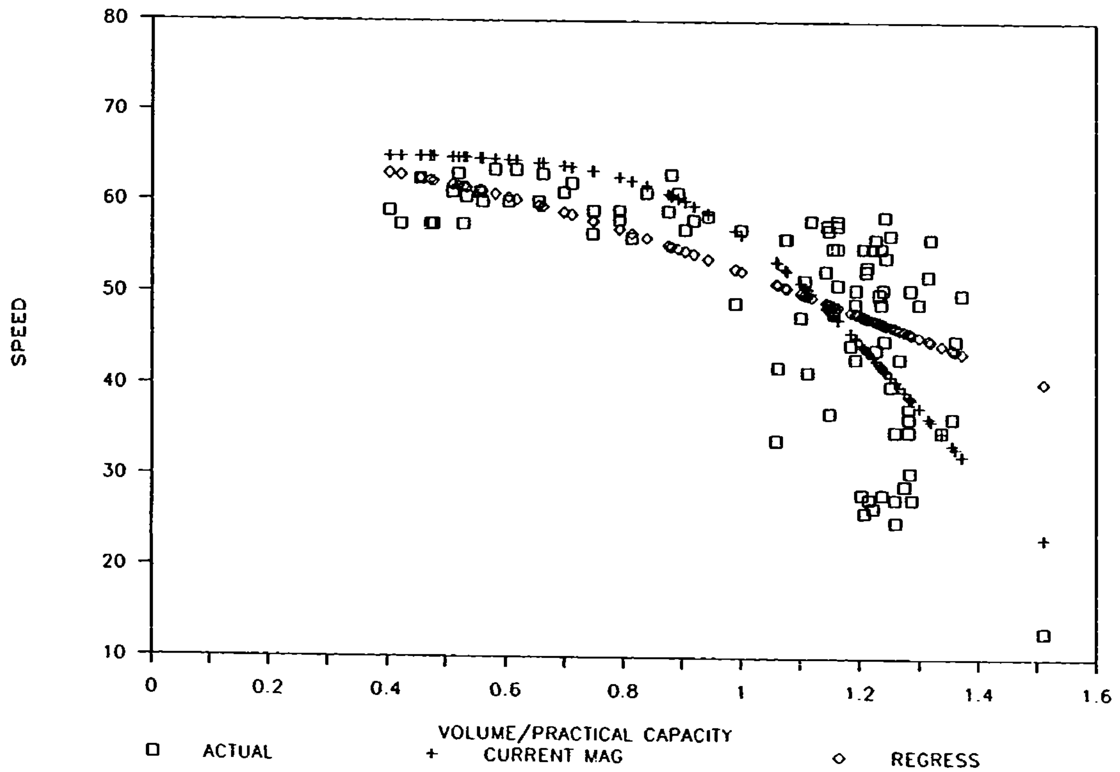


FIGURE 6a

COMPARISON OF FITTED SPEED-VOLUME CURVE WITH ACTUAL DATA FROM PHOENIX FREEWAYS -1986 TRAVEL SPEED STUDY DATA FROM I-10 AND I-17

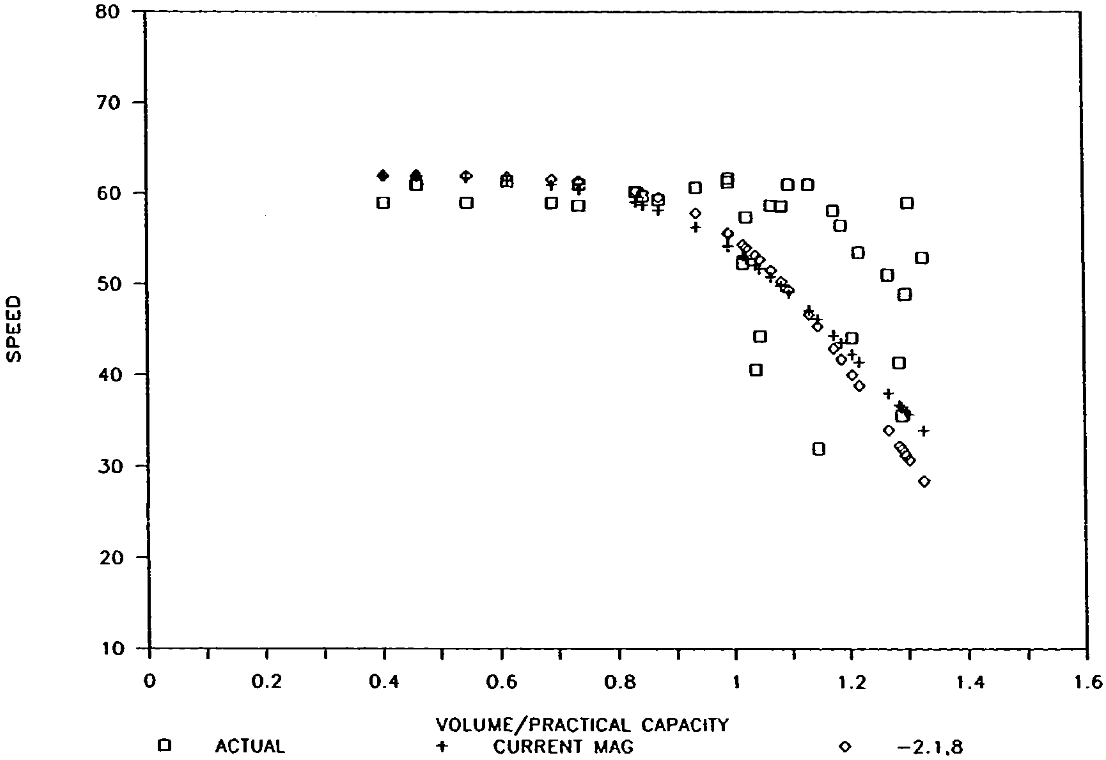


FIGURE 6b

COMPARISON OF FITTED SPEED-VOLUME CURVE WITH ACTUAL DATA FROM PHOENIX FREEWAYS - 1986 ADOT DATA FROM I-17

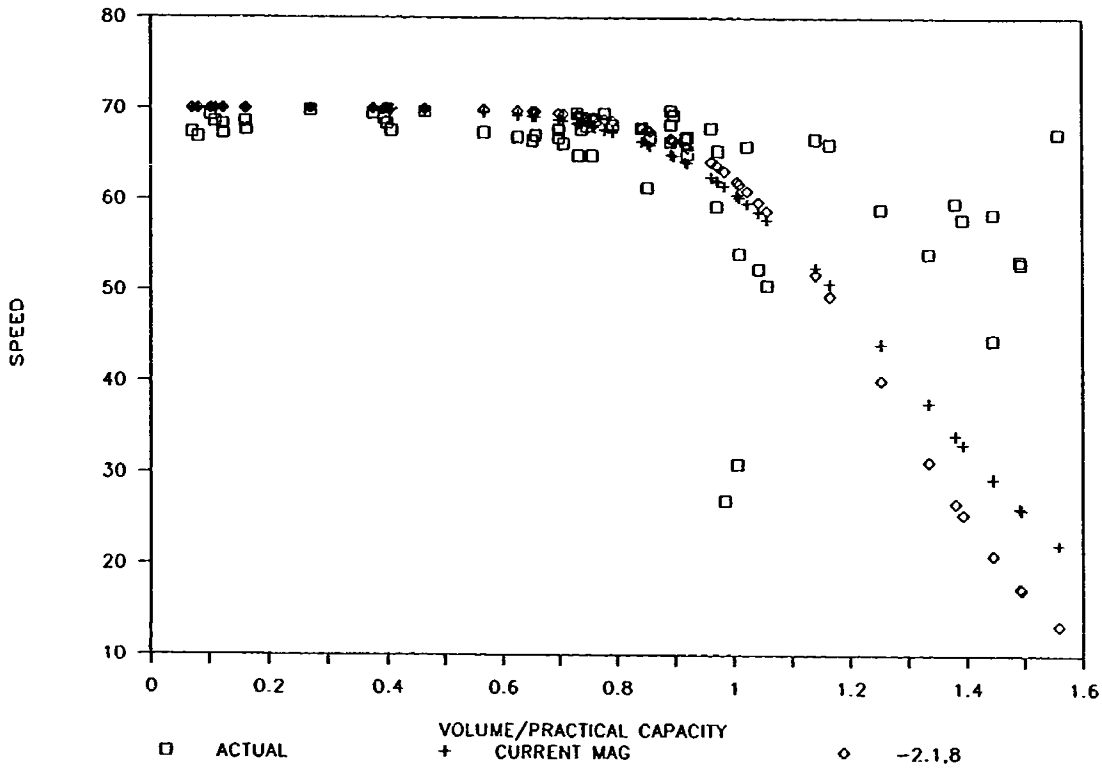
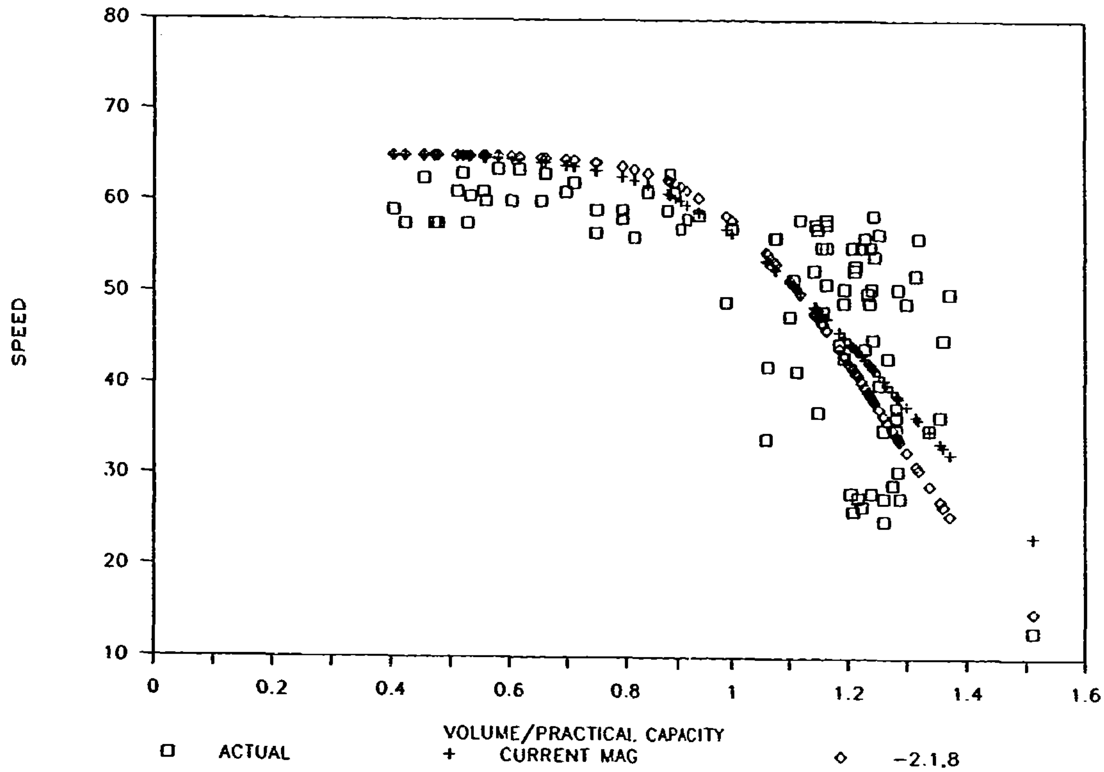


FIGURE 6c

COMPARISON OF FITTED SPEED-VOLUME CURVE WITH ACTUAL DATA FROM PHOENIX FREEWAYS - 1981 MAG/ADOT DATA FROM I-17



Although the three fitted curves have different free-flow speeds, there is a fairly consistent set of parameters which differs significantly from the parameters currently used by MAG. The parameters $\alpha = -.1225$ and $\beta = 8$ produce a reasonable fit to each of the three plots and reflect significantly more curvature in the function as the value of V/C approaches 1. This is consistent with the general theoretical shape of the speed-volume curve and the parameters identified by the curve fitting are recommended for use with freeways and expressways.

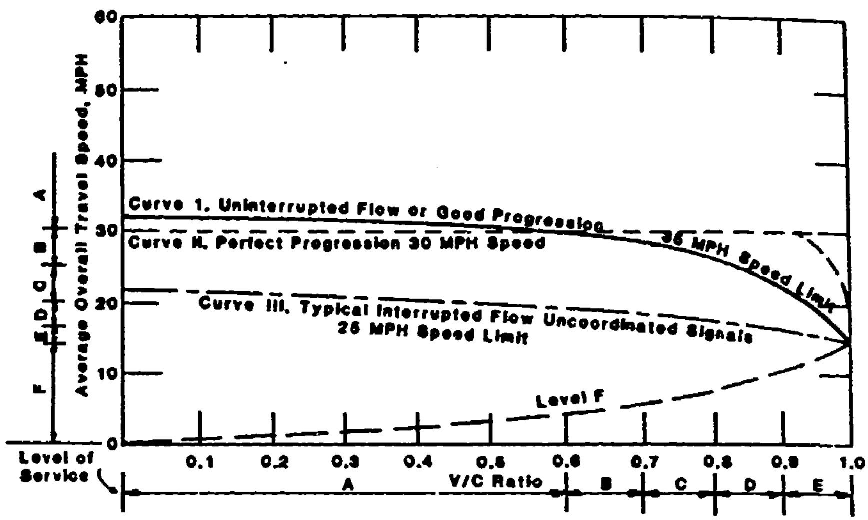
The lack of suitable new data for arterials and collectors in Phoenix prohibits the estimation of a new relationship. Some new national data are available for arterials, however, and were reported in the form of the Figure 7 taken from the National Cooperative Highway Research Report 255, "Highway Traffic Data for Urbanized Area Project Planning and Design," (1982). The curve that appears most relevant for generalized speed estimation in Phoenix appears to be Curve I. While the NCHRP report does not present the parameters that correspond to the three curves, curve fitting suggests the following parameters:

$$\alpha = .1513$$
$$\beta = 7$$

These parameters are recommended for use with the free-flow speeds currently used by MAG. A comparison of average off-peak speeds from the 1986 Travel Speed Study with the free-flow speeds currently used by MAG revealed no significant difference.

Figure 7

SPEED VOLUME CURVES FOR SURFACE ARTERIALS



Source: NCHRP Report # 255

A significant issue that arises in predicting speeds for future-year forecasts concerns the manner in which speeds are predicted for values of the V/C ratio at or greater than one. Because this condition does not occur in reality, the development of a functional relationship from actual data is not possible. To allow for future-year forecasts to be produced with V/C ratios that exceed one, a functional relationship must be constructed which assigns speed values for these higher values of the V/C ratio. MAG currently does this by applying the rule:

If $V/C <= 2$ then $\beta = 6$

If $V/C > 2$ then $\beta = 4$

While this rule results in positive values of speed for all values of the V/C ratio, an alternative formulation can reflect the more rapid deterioration of speeds at values of V/C near one yet always produce a positive value for speed. The following functional form for values of V/C greater than one produces an "S"-shaped curve that approaches the speed S_L as V/C increases.

If $V/C \leq 1$, $S = S_o / [1 + \alpha(V/C)^{\beta}]$

If $V/C > 1$, $S = S_L + q(V/C)^k$

where

S_L = maximum speed, and $q = S(\text{at } V/C=1) - S_L$

These peak-hour-speed functions, which were presented in an earlier project memorandum, have been modified in two ways:

- The functions have been made consistent with the existing MAGTPO procedure, which uses practical capacity rather than possible capacity. Practical capacity is equal to 0.75 * possible capacity. This has led to the use of new parameters for the low volume/capacity speed models.

- The functions for high volume/capacity ratios have been reformulated to provide the same values of speed as the functions for low ratios at their common point, to make the limiting speed value a specified fraction of the free-flow speed, and to reflect the revision in the definition of capacity described above. Also, in UTPS, the functions are stated in terms of travel times T and T_o rather than speeds S and S_o. The revised functions are the following:

1. <u>For $0 \leq V/C' \leq 1.333$:</u>

$$T = T_o \, [1 + \alpha \, (V/C')^{\beta}]$$

where:

T = predicted link travel time at specified V/C';
T_o = free flow link travel time;
V = hourly link volume;
C' = practical hourly link capacity (= 0.75 * C), where C is possible link capacity; and
α, β = estimated parameters.

2. <u>For $V/C' > 1.333$</u>

$$T = \frac{T_o}{R + W \, (V/C')^k}$$

where the new variables are:

$R = S_L/S_o$, the ratio of limiting speed S_L to free-flow speed S_o

$$W = \frac{\dfrac{1}{1 + \alpha\,(1.333)^{\beta}} - R}{(1.333)^{k}}$$

K = estimated parameter

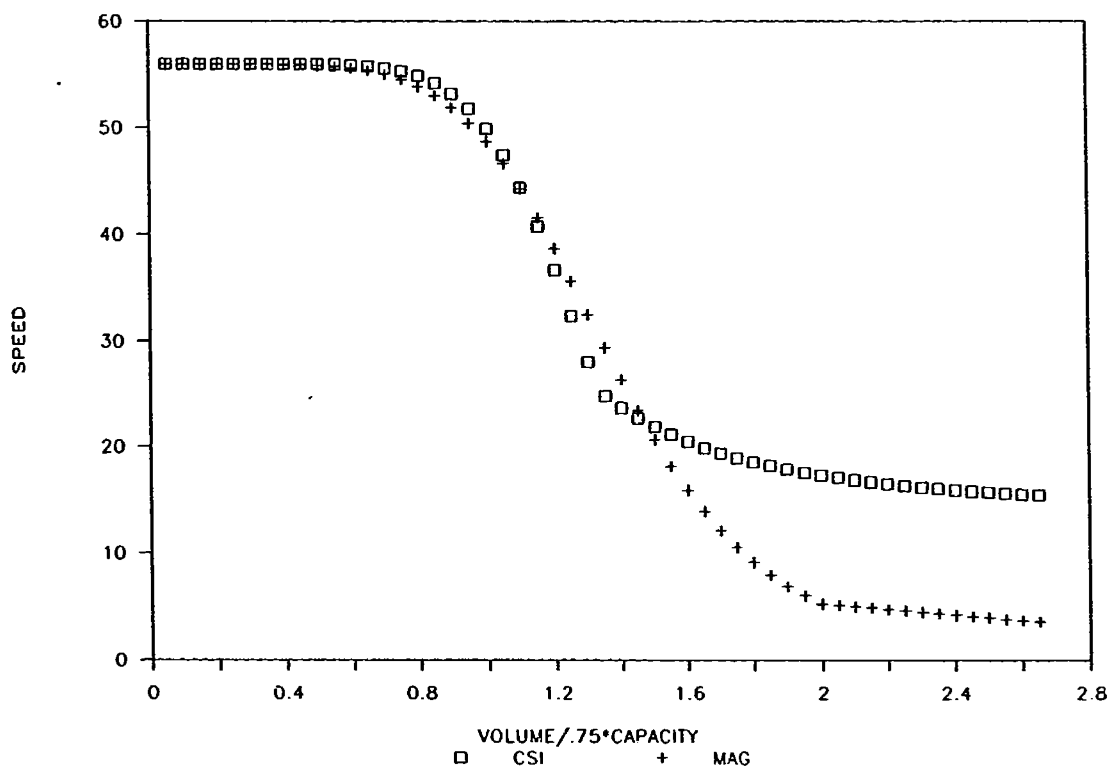
The following parameters are recommended for these models:

Parameter	Facility Type: Freeways and Expressways	Arterials and Collectors
α	0.1225	0.1513
β	8	7
R	0.25	0.25
k	-3	-3
W	0.4736	0.5184

These functions have been implemented in the UROAD program. They are used each time link travel times are updated during the assignment process. The parameters listed above are provided as default values in the program. With the exception of W, these default values can be overridden by user-specified parameters to UROAD. In each case, the revised UROAD computes W using the relationship given above. Figure 8 provides a comparison of the new, recommended model for freeways with the model currently used by MAG.

FIGURE 8

COMPARISON OF RECOMMENDED SPEED-VOLUME RELATIONSHIP FOR FREEWAYS WITH RELATIONSHIP CURRENTLY USED BY MAG



5.0 VALIDATION AND TRANSFERABILITY

5.1 VALIDATION

A validation of the procedures recommended in this project was performed by running a UTPS assignment for the combined set of recommended procedures and for each of the variations described in Section 3.2. A number of descriptive statistics from each of the assignments were recorded and compared to a baseline run made using the procedures used by MAG prior to this study. In all, six complete assignments were run and are compared. They are

1. **Baseline** - MAG's 24-hour trip tables, no peak spreading, peak-hour volumes based on a single area-wide factor, no new speed-volume functions.

2. **New Trip Table** - Same as Run 1 but using a new 24-hour trip table with new corrections for under-reporting.

3. **24-hour Peak Spreading** - Same as Run 2 but with a peak-spreading model that predicts peak-hour volume as a function of 24-hour volume and 24-hour V/C ratio and new speed-volume functions used.

4. **24-hour Trips, 3-hour Peak Spreading** - Same as Run 3 but using a 3-hour peak spreading model and using a set of capacity-based factors to convert 24-hour volumes to 3-hour peak volumes.

5. **3-hour Trips, 3-hour Peak Spreading** - Begins with the development of 3-hour peak-period trip tables based on travel by trip purpose then applies a 3-hour peak spreading model.

6. **3-hour Trips, 3-hour Peak Spreading, Weighted Average Volumes** - Same as Run 5 but weighted average volumes are used in determining travel times in UROAD rather than the peak-hour trips.

The results of the comparison are presented in Table 16. Differences in the statistics reported reflect differences in the trip tables used, new speed-volume functions, whether peak-spreading is performed, how the peak spreading is performed and the volumes used in calculating intermediate travel times for the assignments in UROAD.

The output on which the comparisons in Table 16 are made was always peak-hour volumes and peak-hour speeds. For Runs 1 and 2, the peak-hour volume for each link is always 10 percent of the 24-hour volume which is how the peak-hour volumes are calculated for the assignment and how peak-hour speeds are determined. MAG does have available link-specific K factors for use in design analysis and these factors do provide more accurate estimates of peak-hour volumes on a link specific basis than the constant 10-percent factor.

Seven statistics are compared in Table 16:

1. **Peak-hour Vehicle Miles Traveled (VMT) Assigned** - The sum of the peak-hour VMT over all links in the network.

2. **Average Estimated Peak-hour Speed** - Weighted average of peak-hour speeds over all links in the network.

3. **The Ratio of Estimated to Observed Vehicle Hours Traveled (VHT)** - Comparison for all links for which 1986 speed measurements were available.

4. **Percent Root Mean Square Error for Speeds** - Calculated for all links for which 1986 speed measurements were available.

5. **The Ratio of Estimated to Observed VMT** - Comparison for all links for which 1985 or 1986 traffic counts were available.

6. **Percent Root Mean Squared Error for VMT** - Calculated for for all links for which 1985 or 1986 traffic count were available.

Table 16

COMPARISON OF VALIDATION ASSIGNMENT RUN FOR ALTERNATIVE PROCEDURES

Run No.	Description	Peak-Hour VMT	Average Speed	EVHT/ OVHT	% RMSE (Speed)	EVMT/ OVMT	% RMSE (VMT)	% RMSE Screenline
1	Baseline - MAG 24-hr. Trips, No Peak Spreading	3,821,319	11.94	2.900	56.0	1.164	41.9	50.4
2	New 24-hour Trips, No Peak Spreading	3,682,685	13.44	2.478	52.6	1.112	38.4	43.2
3	24-hour Trips, 24-hr. Peak Spreading	3,461,338	18.53	1.677	46.0	1.009	35.2	38.0
4	24-Hour Trips, 3-hour Peak Spreading	3,254,324	19.49	1.592	42.5	0.968	31.6	32.1
5	3-hour Trips, 3-hour Peak Spreading	3,080,075	19.63	1.564	39.7	1.021	35.4	34.3
6	3-hour Trips, 3-hour Peak Spreading-Weighted Average Volume	3,076,834	20.82	1.451	36.6	1.022	35.4	34.1

7. Screenline Percent Root Mean Squared Error - Calculated for screenlines established by MAG.

The comparison of assigned VMT shows a variation of about 25 percent over the six runs with the VMT consistently decreasing with each model improvement added. This generally reflects the effect of the peak-spreading models that shift travelers out of the peak hour under congested conditions. Each improvement appears to result in more travelers shifting out of the peak hour.

One of the principal concerns that motivated this study was that previous MAG assignments that matched observed 24-hour VMT closely produced peak-hour speeds that were significantly below observed speeds. The comparison of average travel speeds in Table 16 shows a significant improvement in the estimation of speed with each improvement added. The final average speed with all improvements added (20.82 mph) is almost twice the average speed resulting from the currently-used procedures and trip tables. The improvement in the estimation of speeds is also reflected in the the ratio of estimated to observed vehicle hours of travel and in the percent RMSE for link speeds. Both show consistent and significant improvement with each improvement added. The improvement reduces the over-estimation of VHT by one-half and reduce the percent RMSE for speed by 35 percent.

The comparison of the ratio of estimated to observed VMT indicates a significant improvement resulting from the addition of the peak-spreading model, but only minor differences between the four variations that employ peak-spreading models. For these four variations, the estimated VMT is within 3.2 percent or less of the observed VMT in each case. This is in comparison to a 16.4 percent over-estimation using the current procedures. The same conclusions can be drawn from the comparison of percent RMSE for VMT screenlines (also based on VMT).

The comparisons in Table 16 provide strong evidence that each of the improvements recommended in this study are warranted and can produce significant improvement in peak-hour assignments. Additional fine-tuning of the models can be performed by adjustments to the ramp-delay models, the time-distance trade-offs in the path-building procedure, or the speed-volume functions (if new data become available). With such fine-tuning, further calibration can be made to match observed values more closely for specific facility types, for specific area types, or for specific corridors.

5.2 TRANSFERABILITY

General

Because travel patterns vary significantly and not completely understandably from one urban area to another, the safest means of using the results of this project in another city would be to repeat the work reported here using only data representing this city. This would require having available each of the following kinds of travel data for the new urban area:

- Travel survey data, including information from a home interview survey, external cordon surveys, and special generator (for airport trips, for example) surveys.
- Highway traffic count data, including both a large number of locations for which current data are available, and a few locations (at least one location per major facility type) for which information is available for ten or more consecutive years in the past. In both cases, both hourly volumes for peak A.M. and P.M. periods and daily volumes are required.
- Highway speed data, consisting of simultaneous measurements of speeds and volumes for a large sample of highway facilities of varying types and varying volume-capacity ratios.

Because this ideal situation with respect to data availability rarely obtains in any urban area, and because the costs of redoing what was done in Phoenix would be significant, it is important to explore less data intensive and less costly means of transfering the modeling strategies developed in this project to other urban areas. Recognizing the inherent tradeoffs between the reductions in costs and possible reductions in precision and accuracy involved in alternative approaches, a number of possible approaches are described briefly in the paragraghs which follow. They are ordered from the least costly in terms of data requirements and development time to the most costly.

1. Complete Transfer of the Phoenix Models

   If planners in another urban area have no current tools to predict highway volumes by time of day, have reason to believe that volume spreading during peak periods will be significant in the future, but have insufficient data of the types described above, they would be able to use the results of this project, including its modeling strategies, model parameters, and modifications to UTPS travel forecasting programs. In this way they could implement a complete new approach to peak-period/peak-hour volume and speed estimation. To the extent that travel patterns and behavior in Phoenix and the other urban areas from which data were used in this project are representative of local conditions, this approach would provide a useful tool for local planning at a relatively small cost.

   This approach would be a reasonable one for Tuscon, for example, which is likely to be highly similar to Phoenix in terms of current and expected future travel behavior. It might also be appropriate in other large western cities with either current or expected future levels of traffic congestion similar to those in Phoenix.

2. Combining Portions of the Phoenix Models with Available Local Data

In urban areas with some portion of the data required for this project, as described above, but not all, it will be quite easy to use the overall model structure developed here, but to re-estimate selected models using local data. (Actually, this approach would parallel what was done in Phoenix, where time-series traffic count data was used from other western cities and volume-speed information representing typical national conditions was used, in addition to local data.) Because the three models developed in this project are easily separable, there would be no difficulty in using revised parameters in one or two of the models plus the parameters reported in this project for the other(s).

Based on considerations of the expected range of applicability of the Phoenix models rather than issues of data availability in a new urban area, the first priority in estimating new parameters would be given to the a and maximum peaking parameters of the Phoenix volume-spreading model. These are strongly dependent on the specific capacities per lane used to describe links by facility type, area type, and number of lanes in the Phoenix traffic assignment network; as well as on the average values of one-hour to three-hour peaking factors and volume-capacity ratios presently observed in Phoenix. To the extent that these parameters of related parts of the travel forecasting process and these observations of traffic patterns differ for other urban areas, the models would be significantly improved by using local information to develop the required values of these parameters.

Next in importance for parameter re-estimation would be the purpose-based factors used to convert daily travel to three-hour peak travel. These factors depend on local definitions and classifications of trip purposes, as well as on differences in time-of-day travel patterns from one region to another.

The remaining parameters of the models--b in the volume-spreading model and the coefficients of the volume-speed functions--would have the lowest priority for re-estimation because they are currently based on data from many cities. Unless ideal local sources of the information required to obtain these parameters on an area-specific basis already exist, planners in other urban areas are advised to retain the values found in this study.

If any model parameters are revised to reflect local conditions in other urban areas, changes of various types will be required in the programs which implement the models, or in the input data required by these programs. These changes include the following:

- If purpose-based peak period factors are revised, the input data to UMATRIX, which includes these factors directly, can be modified to reflect the changes.
- If the parameters of the volume-spreading models are changed, new capacity-specific values, as well as look-up tables relating these values to the full set of capacities per lane in the local highway network, must be used to modify the Fortran code of the UROAD user-coded subroutine in UTPS.
- If the parameters of the volume-speed functions are revised, the new parameters can be input to UROAD via the USER variables documented in Appendix B.

3. Development of a "National Model"

Perhaps the ultimate extension of the models developed in this project to other urban areas would involve their generalization to create a "national model", taking the Quick Response System (15) as a pattern. This would involve combining the existing models with information in the UMTA reports "Characteristics of Urban Travel Demand" (1) and "Characteristics of Urban Transportation Systems" (16) to provide tables of each of its parameters as these are likely to vary by urban area type and size. Although this would involve a significant amount of effort, it would provide all urban areas with versions of the models developed in this project which, in the absence of local data and model estimation, could be used to estimate peak hour highway flows with acceptable levels of accuracy.

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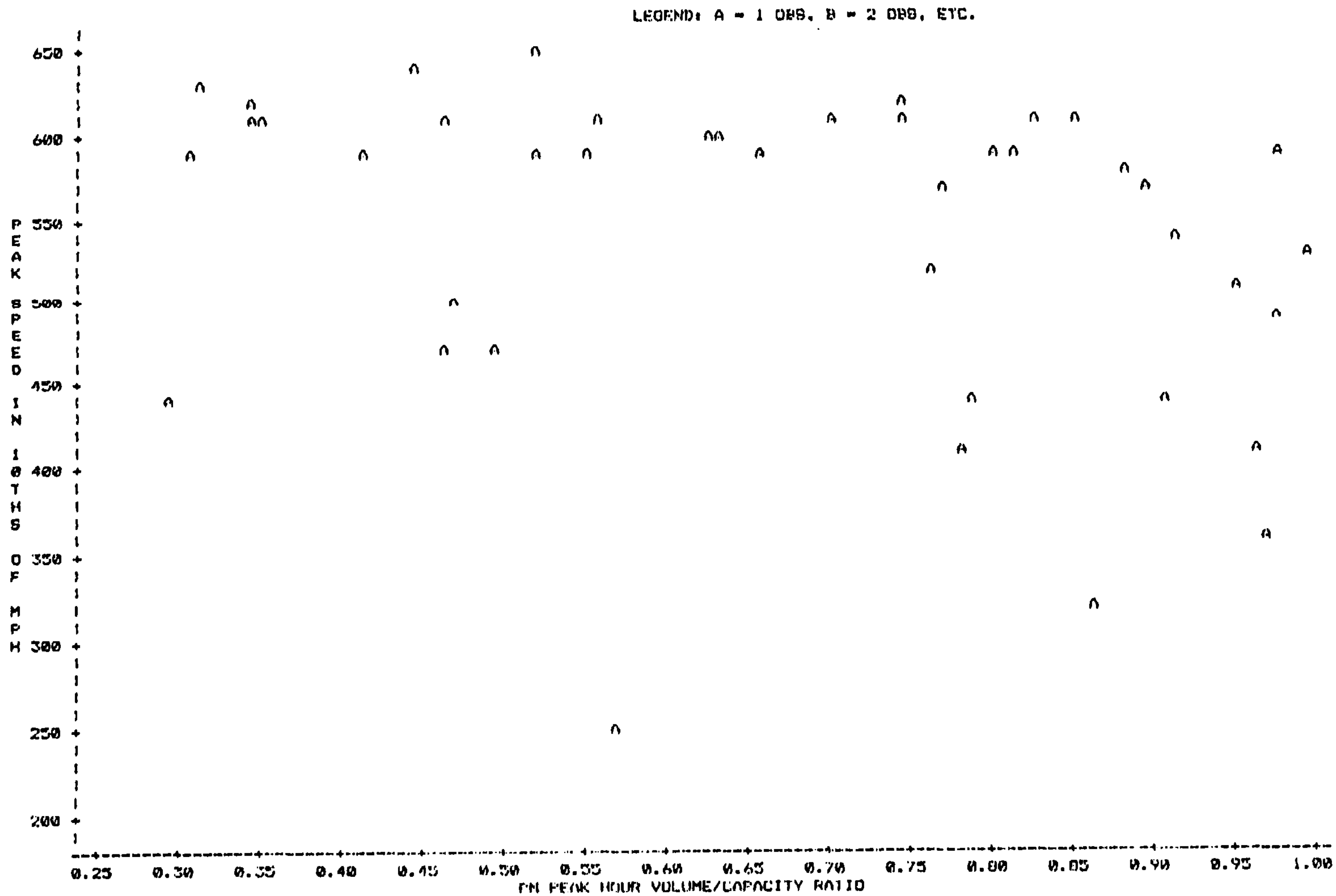
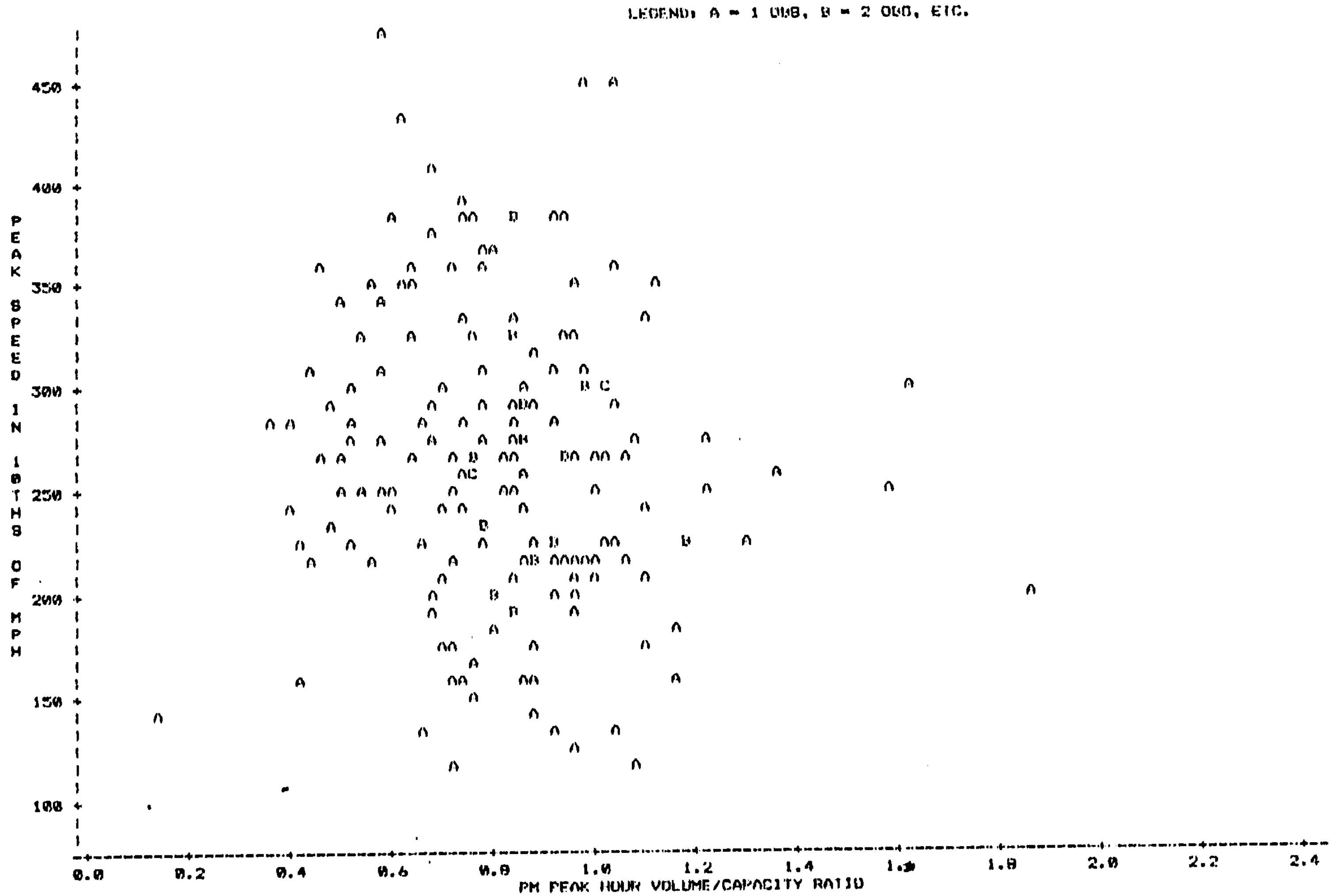
APPENDIX A

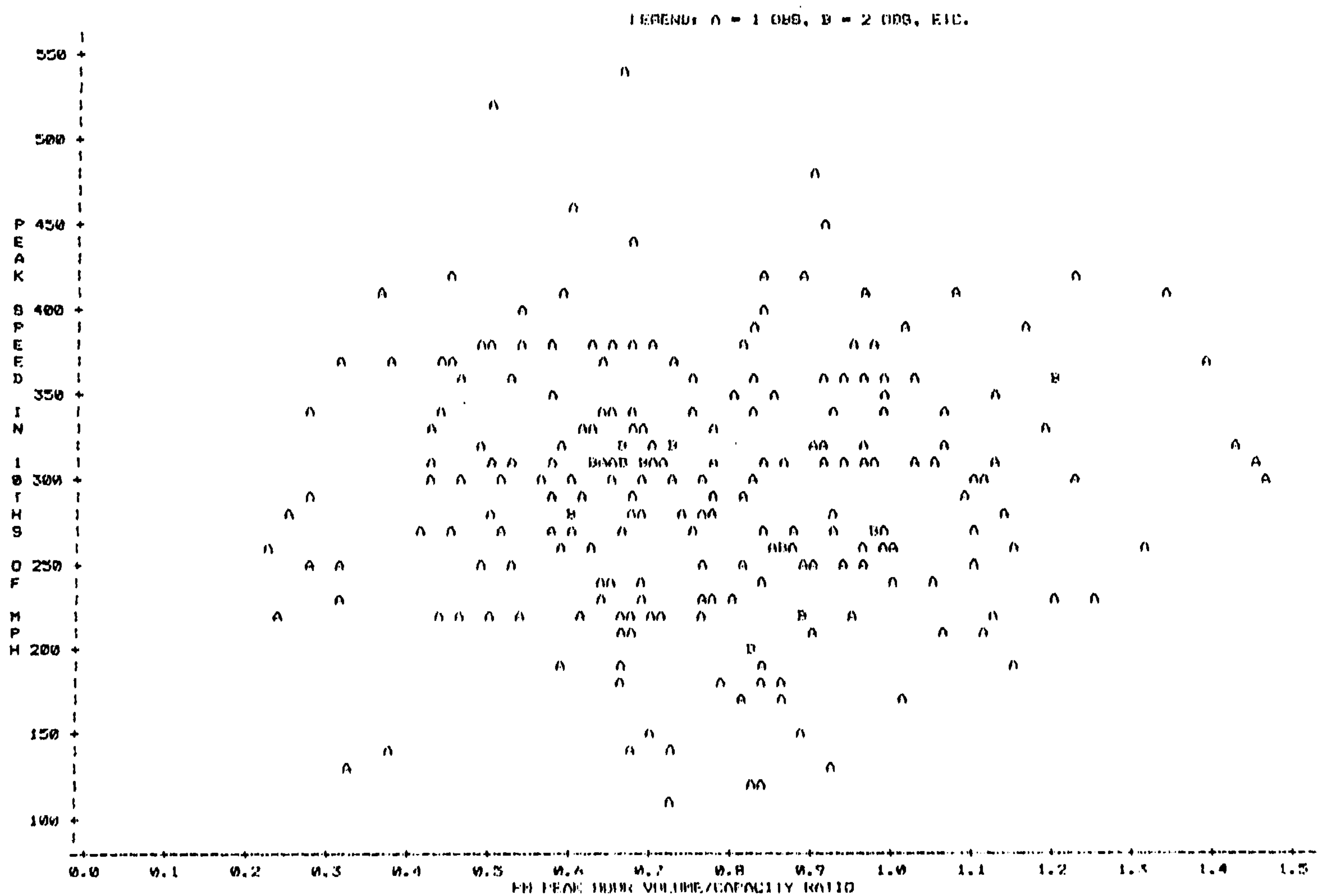
PLOT OF OBSERVED PEAK-HOUR SPEED-VOLUME RELATIONSHIPS FOR FREEWAYS AND ARTERIALS



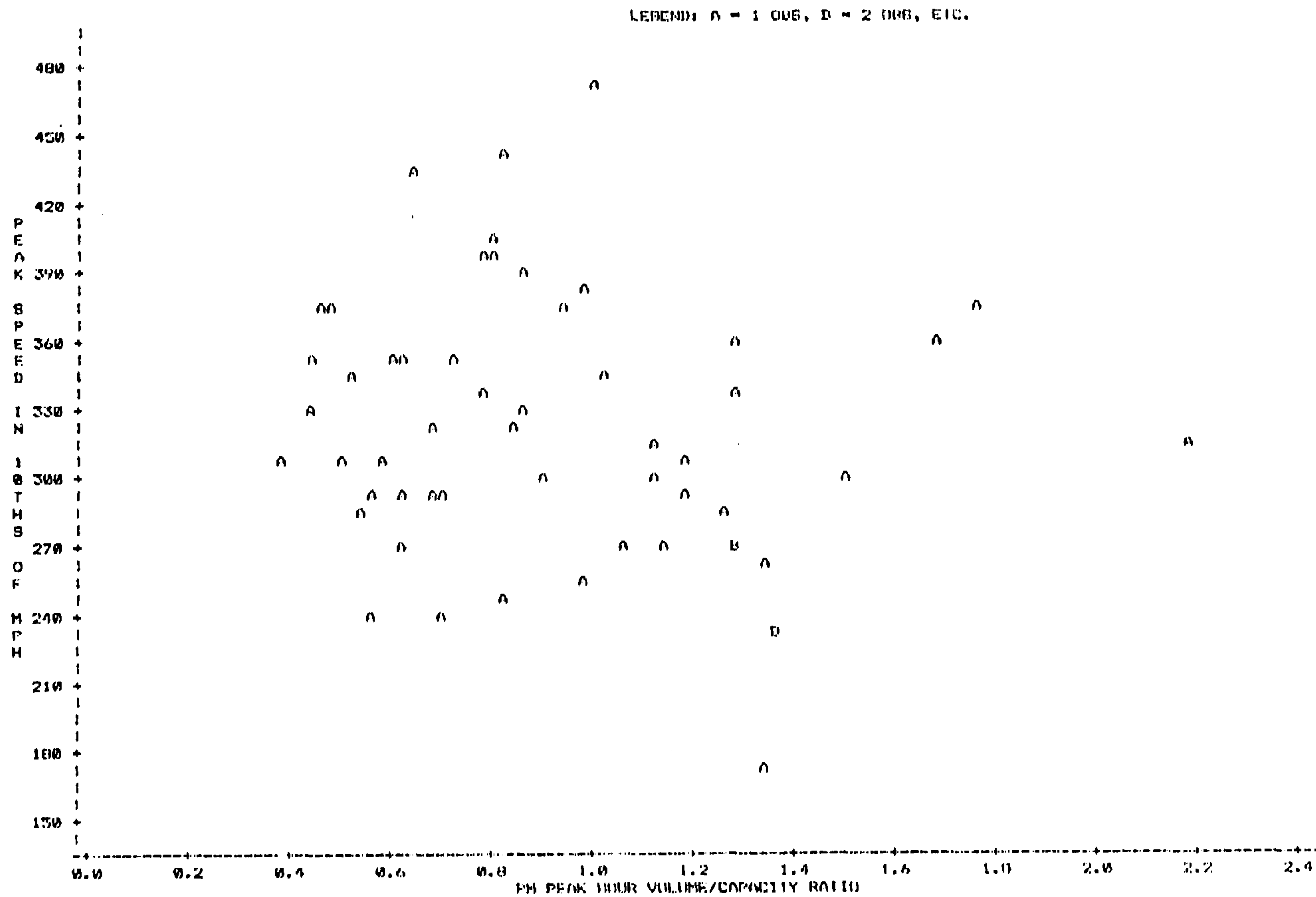
PLOT OF OBSERVED PEAK-HOUR SPEED-VOLUME RELATIONSHIP FOR FREEWAYS - PHOENIX 1985/86



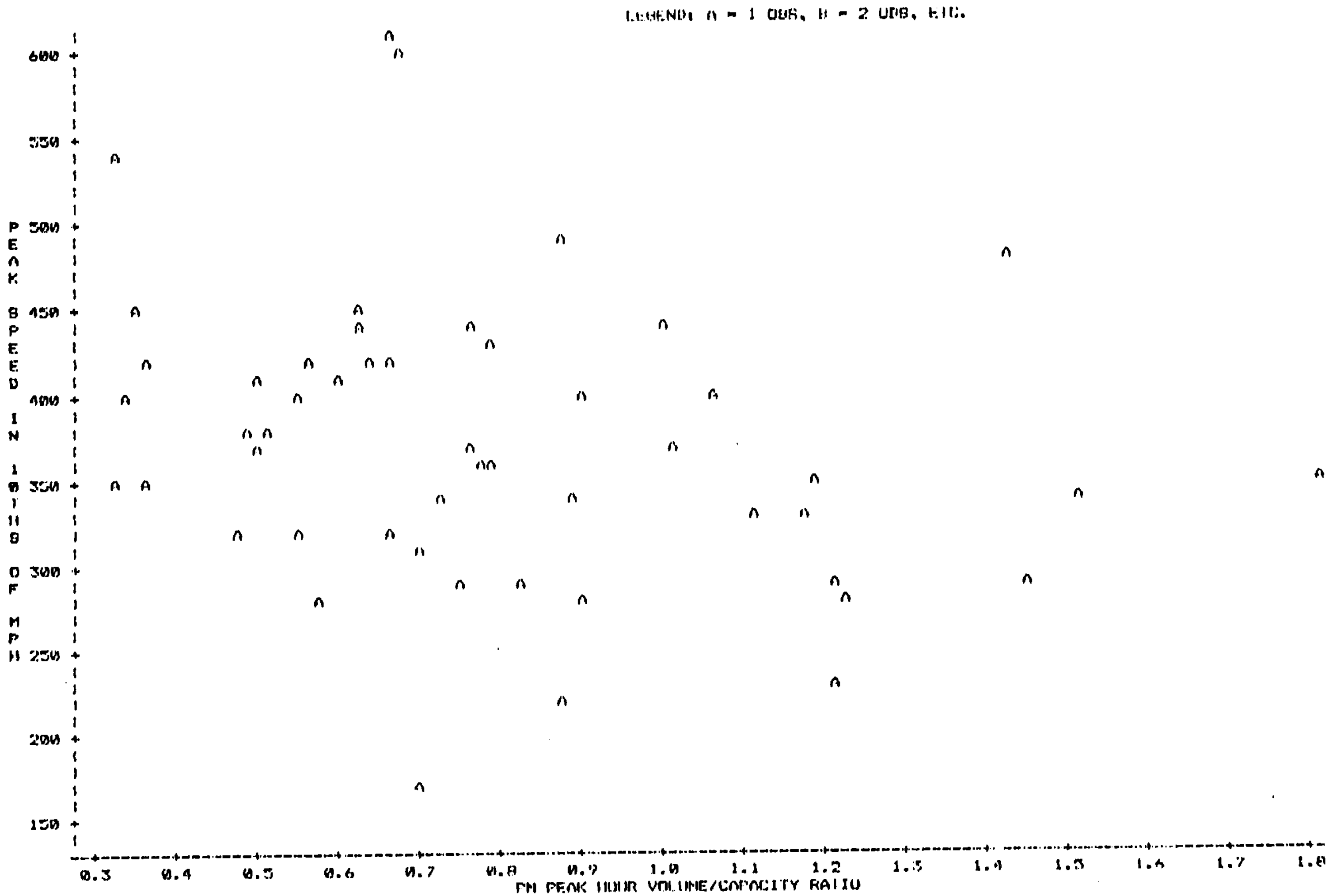
PLOT OF OBSERVED PEAK-HOUR SPEED-VOLUME RELATIONSHIP FOR ARTERIALS - PHOENIX 1985/86
AREA TYPE 1



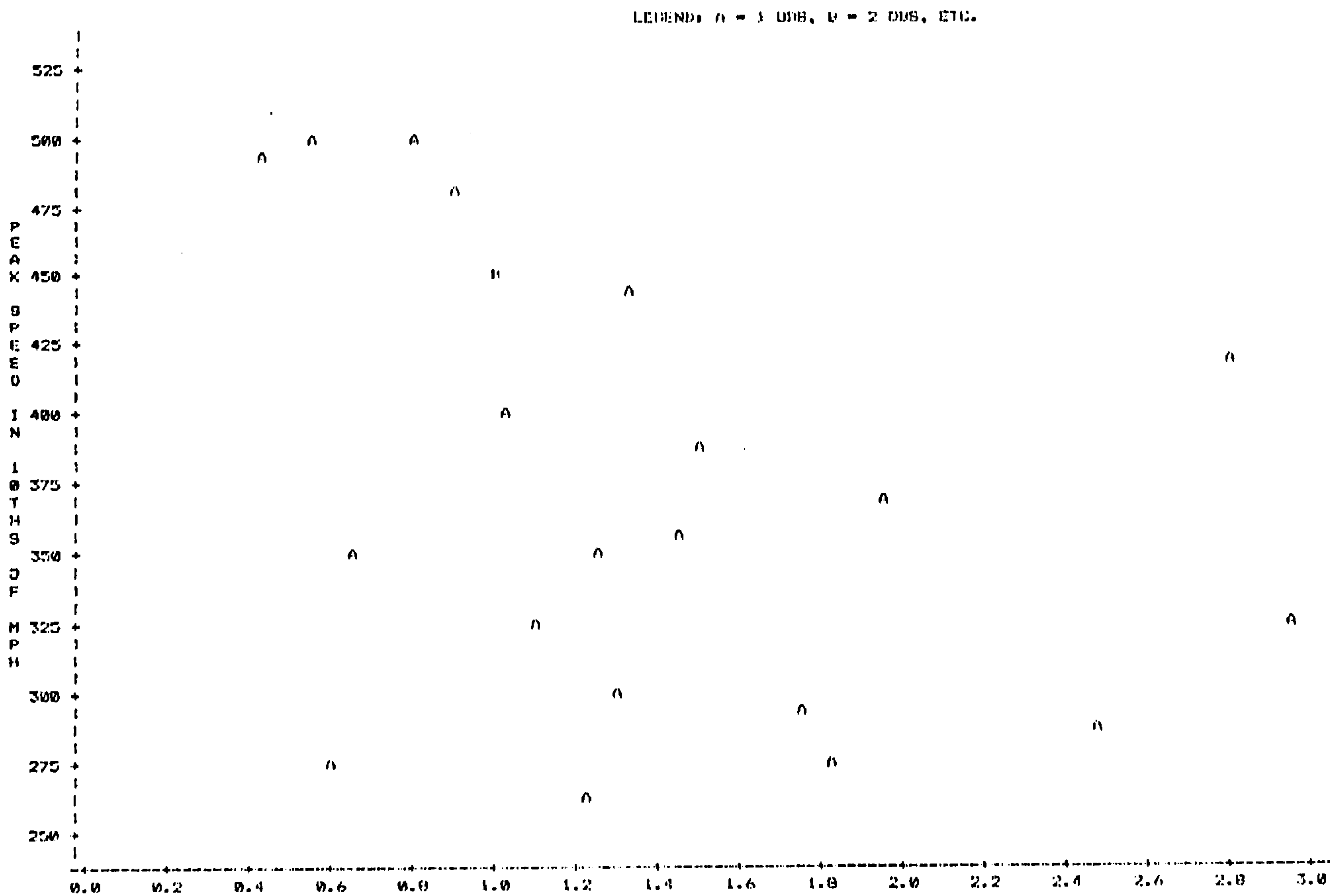
PLOT OF OBSERVED PEAK-HOUR SPEED-VOLUME RELATIONSHIP FOR ARTERIALS - PHOENIX 1985/86
AREA TYPE 2



PLOT OF OBSERVED PEAK-HOUR SPEED-VOLUME RELATIONSHIP FOR ARTERIALS - PHOENIX 1985/86
AREA TYPE 3



PLOT OF OBSERVED PEAK-HOUR SPEED-VOLUME RELATIONSHIP FOR ARTERIALS - PHOENIX 1985/86
AREA TYPE 4



PLOT OF OBSERVED PEAK-HOUR SPEED-VOLUME RELATIONSHIP FOR ARTERIALS - PHOENIX 1985/86
AREA TYPE 5

APPENDIX B

REVISIONS TO UROAD DOCUMENTATION

The material included in this appendix represents additions to the UTPS UROAD program documentation provided by UMTA. This appendix should be used in conjunction with the UMTA material by the user of the revised UROAD procedures.

File Table

One additional file must be defined to run the new UROAD procedures. In the terms used in the UTPS UROAD program documentation, it is an OTHER file with the following characteristics:

File Name: FT22F001

Contents/Function: Used for temporary storage of link parameters needed to apply the peak-spreading models described in Section 3.2

3.2 Keyword Table

Eleven USER parameters may optionally be specified: all are real variables:

Keyword	Default	Value or Purpose
USER(1)	4.0	Time period and type of assignment (3.2):* 1 = A.M. peak period trips, 3-hour volume-spreading 2 = P.M. peak period trips, 3-hour volume-spreading 3 = 24-hour trips, 24-hour volume-spreading Any other = 24-hour trips, 3-hour volume-spreading
USER(2)	0.25	R, ratio of limiting link speed to free-flow speed (3.3)
USER(3)	8.0	Beta in speed function for freeways and expressways (3.3)
USER(4)	0.1225	Alpha in speed function for freeways and expressways (3.3)
USER(5)	7.0	Beta in speed function for arterials (3.3)
USER(6)	0.1513	Alpha in speed function for arterials (3.3)
USER(7)	7.0	Beta in speed function for collectors (3.3)
USER(8)	0.1513	Alpha in speed function for collectors (3.3)
USER(9)	-3.0	Kappa in speed function for high volume/capacity ratios (3.3)
USER(10)	0.0	Switch to control time period for final link volumes (3.2): = 0: volumes for entire assignment period (3 hours or 24 hours) = 1: volumes for peak hour only

Keyword	Default	Value or Purpose
USER(11)	0.0	Switch to control usage of peak-hour or weighted average hourly volumes during peak period assignments (3.2): = 0: weighted average hourly volume during the peak period (not available for 24-hour assignments with 24-hour peak spreading--when USER(1) = 3) = 1: peak-hour volumes

*See the indicated Section of this memorandum for specific values or for further explanation of how the parameter is used.

Example Runs

The setups for two example runs are shown below. Example Run #1 represents the final test run described in Section 5.1, in which three-hour peak-spreading is performed on a three-hour peak-period trip table, with weighted average volumes used in determining travel times in UROAD and reported at the end of the assignment process. Example Run #2 demonstrates how alternative assignment options can be selected with the USER keywords. This example reflects three-hour peak-spreading performed on a 24-hour trip table, with peak-hour volumes used to determine travel times in UROAD; followed by the output of 24-hour link volumes.

Example Run No. 1

ADOTEX1.PRN printed on 3-3-88 at 10:50 AM

```
//EXAMPLE1       EXEC  UROAD,CORE=3000K,
//                     Z1='DSN=TP242.MAGTPO.Y85BOF.CS1HRZ1',
//                     UNITZ1='3350,VOL=SER=DOT487',
//                     J1='DSN=TP242.MAGTPO.Y85C.VEHICLE.CSO$D',
//                     UNITJ1='3350,VOL=SER=DOT487'
//UROAD.STEPLIB    DD  DSN=TP242.MAGTPO.UROADCS.MAR87,DISP=SHR,
//                     UNIT=3350,VOL=SER=DOT471
//UROAD.FT22F001   DD  UNIT=&UNITSCR,SPACE=(TRK,(10,19)),
//                     DCB=(RECFM=VBS,LRECL=1004,BLKSIZE=1008)
//UROAD.SYSIN      DD  *
 EXAMPLE RUN # 1:  3-HR TRIPS, 3-HR PK SPREADING, USE WEIGHTED PEAK
                   VOLUMES DURING ASSIGNMENT AND OUTPUT AT END
 &PARAM
          TABLES=103,THETA=0,0,0,0,0,0,0,CDIST=0.07,
          TOLLS=1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,
          1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,
          CATS=25,EPS=.001,USER(1)=2,USER(10)=1,USER(11)=0,
          SERVT=0.060,0.060,0.060,0.060,0.022,0.060,
          0.060,0.060,0.060,0.060,0.060,0.060,0.060,
          0.044,0.040,0.033,0.027,0.022,0.020,
          LAVN=1,ASSIGN='EXAMPLE#1'  &END
 &OPTION  QUEUE=T  &END
 &SELECT
          N = 3260,-3270,6583,7709,
          REPORT=1,4,19  &END
 &DATA
T  152 3747 3749 9999
   .
   .
   .
T 5618 5631 5580 9999
/*
```

Example Run No. 2

ADOTEX2.PRN printed on 3-3-88 at 10:50 AM

```
//EXAMPLE2        EXEC  UROAD,CORE=3000K,
//                      Z1='DSN=TP242.MAGTPO.Y85BOF.CSMAXZ1',
//                      UNITZ1='3350,VOL=SER=DOT487',
//                      J1='DSN=TP242.MAGTPO.Y85C.VEHICLE.CSO$D',
//                      UNITJ1='3350,VOL=SER=DOT487'
//UROAD.STEPLIB    DD   DSN=TP242.MAGTPO.UROADCS.MAR87,DISP=SHR,
//                      UNIT=3350,VOL=SER=DOT471
//UROAD.FT22F001   DD   UNIT=&UNITSCR,SPACE=(TRK,(10,19)),
//                      DCB=(RECFM=VBS,LRECL=1004,BLKSIZE=1008)
//UROAD.SYSIN      DD   *
 EXAMPLE RUN #2:   24-HR TRIPS, 3-HR PEAK SPREADING, USE PEAK HOUR
                   VOLUMES DURING ASSIGNMENT, OUTPUT 24-HR VOLUMES
 &PARAM
          TABLES=101,THETA=0,0,0,0,0,0,0,CDIST=0.07,
          TOLLS=1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,
          1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,
          CATS=25,EPS=.001,USER(1)=4,USER(10)=0,USER(11)=1,
          SERVT=0.060,0.060,0.060,0.060,0.022,0.060,
          0.060,0.060,0.060,0.060,0.060,0.060,0.060,
          0.044,0.040,0.033,0.027,0.022,0.020,
          LAVN=1,ASSIGN='EXAMPLE#2'  &END
 &OPTION  QUEUE=T  &END
 &SELECT
          N = 3260,-3270,6583,7709,
          REPORT=1,4,19  &END
 &DATA
T  152 3747 3749 9999
   .
   .
   .
T 5618 5631 5580 9999
/*
```

Additional Job Control Language

(1) The new version of UROAD is invoked as follows:

```
// EXEC PGM=UROAD,DSN=TP242.MAGTPO.UROADCS.MAR87,
// UNIT=3350,DISP=OLD,VOL=SER=DOT471
```

(2) The additional file should be defined the same whay that the existing FT09F001 file is defined:

```
//FT22F001 DD UNIT=&UNITSCR,SPACE=(TRK(10,19)),
// DCB=(RECFM=VBS,LRECL=1004,BLKSIZE=1008)
```